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THE UNIVERSITY OF ALBERTA

# THE ORGANIZATION OF LATERALIZED FUNCTIONS IN CONGENITAL HEMIPLEGIA

BY

ANDRE VENTER

©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

IN

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DEPARTMENT OF PEDIATRICS

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## ABSTRACT

This study describes the examination of children with congenital hemiplegia (6 - 16 years) on a wide range of cognitive, neuropsychological, language and visual-spatial tests, and a neurological examination. Use was made of parent questionnaires to gain information on birth history, neurological development, education, socioeconomic status and handedness of family members. Strict inclusion criteria ensured the unilaterality of the lesion. Fifty-one subjects were included in this study, 28 with right hemiplegia (14 male and 14 female) and 23 with left hemiplegia (15 male and 8 female). These two groups were compared to a control group (15 male and 15 female) who were chosen to match the subjects on age at testing, full scale IQ and socioeconomic status.

Subjects were studied to determine the effects of early unilateral hemispheric lesions on lateralized higher cerebral functions, and compensation due to neuroplasticity in the reorganization of these functions. The influence of potentially interacting variables, such as sex, familial sinistrality, severity of the cerebral lesion and intervention was also investigated.

Right hemiplegic subjects, who have left hemisphere lesions, were found to have significantly prolonged latencies on a test of complex syntactic interpretation (Active - Passive Test) as compared to Controls. They also demonstrated significantly poorer performance on the Object Assembly,

Coding tests and the Performance IQ of the WISC-R, as well as the Raven's Progressive Matrices and the Developmental Test of Visual Motor Integration (all considered right hemisphere functions) than the Controls. Left hemiplegics generally performed better on verbal tasks, and poorer on visual-spatial tasks than the Controls, but differences were not statistically significant. No main effects for sex, familial sinistrality, seizures, therapy or severity of the physical handicap, as measured by the function of the affected hand, could be demonstrated. Neurodevelopmental delay and problems during pregnancy emerged as important predictors of cognitive outcome measures. Birth asphyxia was significantly correlated with seizures.

The left-right maturation gradient of the two hemispheres could be responsible for the unexpected results in the right hemiplegics. Injury to the left hemisphere may result in transfer of language functions to the less mature (more plastic) right hemisphere at the expense of visual-spatial skills. With right-sided lesions, visual-spatial skills are not transferred to the left hemisphere which is more mature and less plastic. Language functions are not affected, and the damage is partially compensated for by right intrahemispheric reorganization.

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No major achievement in my life has been accomplished in isolation. Now, as another milestone approaches, it seems appropriate to acknowledge those, without whom, this point would never have been reached.

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# CHAPTER I: INTRODUCTION

In this study, the organization of cognitive function in children with congenital hemiplegia, a form of cerebral palsy, was investigated. Because many issues are involved in research of this nature, the introduction will deal mainly with the implications and limitations of cognitive research using patients with brain injury. In the next chapter, some of the theoretical issues will be discussed in more detail.

## (A) Cerebral Palsy

### (i) Definition

Cerebral palsy is no longer considered a single condition, but a miscellany of clinical syndromes with various causes (Alberman & Stanley, 1984). In general terms, cerebral palsy is a disorder of movement and posture due to a defect or lesion of the immature brain (Bax, 1964; Low & Carter, 1987). By definition then, disorders of short duration, or those due to progressive disease or mental deficiency are excluded. A person with cerebral palsy may also have seizures, mental retardation, developmental delay and learning disabilities. Sensory loss, speech and verbal, as well as perceptual deficiencies may also be associated with the clinical syndrome (Perlstein & Hood, 1957).

### (ii) Epidemiology

The prevalence of cerebral palsy is not known for Alberta, Canada, but there is no reason to suspect that it would differ from other Western countries. In a review by Paneth and Kiely (1984), the average reported rate is about 2.0 per 1000, whether the denominator used is live births or school-age populations. In third world countries, such as Nigeria, the incidence is more than twice as high (Nottidge & Okogbo, 1991). The possibility that there has been a decline in the cerebral palsy rate due to improved neonatal and intensive care has received much publicity, but Paneth and Kiely were unable to demonstrate a consistent trend in this direction. However, in their follow-up study of 'neonates at risk' in Edmonton, Alberta, Robertson and Etches (1988) found that although the number of surviving infants of very low weight (< 1250 g) increased over the study period, the incidence of neurologic impairment fell significantly, so that there was no significant increase in the absolute number of disabled children. The incidence rate for neurological impairment, of which cerebral palsy and mental retardation are the most common, has been set at 13% (Robertson et al., 1988), or 14% for one or more 'major' deficits (Low, Galbraith, Muir, Brookhoven, Wilkinson, & Karchmar, 1985).

### (iii) Research and the Cerebral Palsied

The cerebral palsied have interested a wide range of researchers, not only because of their very specific educational, rehabilitative and socio-emotional needs (Guthrie, 1974), but also because of their specific patterns of cognitive deficits (Cronholm & Schalling, 1968; Nielsen, 1971), especially in visual-spatial perception and visual-motor skills (Bortner & Birch, 1962; Breakey, Wilson, & Wilson, 1974; Marozas & May, 1986; Menken, Cermak, & Fisher, 1987; Newcomer & Hammill, 1973; Simpson, 1974; Wedell, 1960). Studies such as those above have done much to highlight the fact that the cognitive level in these children can be assessed at a young age with reasonable accuracy and with satisfactory test-retest reliability over time (Nielsen, 1971). Deficits, mostly in visual-perceptual skills, have been shown not to be due solely to developmental lag, and had been found even in the absence of mental retardation (Cronholm et al., 1968). The majority of researchers had not distinguished between different clinical syndromes of cerebral palsy (spasticity, choreo-athetosis, and ataxia) that differ in clinical presentation and etiology. In most earlier studies results had either not been analyzed separately for the major groups (Nielsen, 1971), or for the different subgroups (e.g. monoplegia, diplegia, hemiplegia or quadriplegia, Bortner et al., 1962; Breakey et al., 1974; Cronholm et al., 1968; Menken et al., 1987; Newcomer et al., 1973; Simpson, 1974).

## (B) Spastic Hemiplegia

### (i) Definition

In spastic hemiplegia, one of the subgroups of cerebral palsy (Ingram, 1984; Low et al., 1987), involvement of one motor hemicortex results in contralateral weakness of the involved musculature, increased muscle tone, exaggerated tendon reflexes, and a tendency to develop contractures (Powell, Pharoah, Cooke, & Rosenbloom, 1988). In hemiplegia, the arm is usually affected more than the leg (Low et al., 1987).

Generally, spastic hemiplegia is a diagnosis made on clinical neurological findings, but the unilaterality of the brain damage as well as the severity, site and size of the lesion can be identified with specialized non-invasive techniques such as computerized tomographic (CT) brain scan (Cohen & Duffner, 1981; Kertez, Harlock, & Coates, 1979; Kotlarek, Rodewig, & Brull, 1981). Thus, patients with spastic hemiplegia present a "natural" model of "presumed" unilateral brain damage. They can therefore be utilized to investigate particular issues of brain function and response to unilateral injury (Perlstein et al., 1957).

### (ii) Epidemiology

Hemiplegics make up about one third of all individuals with cerebral palsy, and nearly 50% of all the spastic groups (Nottidge et al., 1991; O'Reilly & Walentynowicz, 1981; Perlstein et al., 1957). An equal distribution of hemiplegia across sex or side of lesion has not been found in epidemiological studies (Nottidge et al., 1991; Perlstein et al., 1957). More males than females seem to be affected, and generally more right than left hemiplegia is diagnosed. The reasons for these findings are not clear. The male predominance might be linked to slower rates of maturation, proliferation and myelination of nerve fibers in certain regions in the cerebral cortex in males than females (Andrews, 1977). It has been argued that the relative immaturity of the male brain could place it 'at risk' for a perinatal insult, in contrast to the more mature brain of female neonates (Goldman, 1974). An increased incidence of left hemispheric lesions has been linked to orientation of the head at birth and potential handedness, and a greater incidence of cerebro-vascular accidents in the dominant hemisphere (see discussion in Annett, 1973; Nass, Peterson, & Koch, 1989).

## (C) Issues in the Study of Patients With Unilateral Brain Injury

Studying subjects with unilateral brain injury has been one method utilized to investigate the lateralization of higher cerebral functions. Other methods have included the systematic examination of 'split-brain' and acallossal patients, hemidecorticates and functional asymmetries in normal subjects. This presumed dichotomy (lateralization) of cerebral functions implies that each hemisphere contributes to overall human behavior and understanding, interpretation of sensory input and response to external stimuli and internal processing of thought and perception, but that the hemispheres differ in the way information is dealt with (see review in Springer & Deutsch, 1981). Experimental and clinical investigators of hemispheric asymmetry generally propose that the left hemisphere deals with information in an organizational, syntactic and hierarchic way, and may be better suited to cope with the demands of language. The right hemisphere is proposed to be more synthetic and holistic in its approach to information, and therefore better equipped for tasks requiring visual-perceptual interpretation.

### (i) Limitations of Previous Research

#### (a) Adult Subjects

Because of their accessibility and cooperation, adults have been extensively used in cerebral laterality research (e.g. Basso, Capitani, Luzzatti, & Spinnler, 1981; Cavelli, De Renzi, Faglioni, & Vitale, 1981; De Renzi & Spinnler, 1966; Kertesz & Sheppard, 1981; McGlone, 1977; Newcombe, 1974; Reed & Reitan, 1963; Simpson & Vega, 1971; Smith, 1966; Teuber & Rudel, 1962; Vega & Parsons, 1969;

Warrington & James, 1967). Results of studies investigating aphasia (Basso et al., 1981; Kertesz et al., 1981; McGlone, 1977), language and verbal performance on the Wechsler Adult Intelligence Scale (WAIS) (McGlone, 1977; Newcombe, 1974; Reed et al., 1963; Simpson et al., 1971; Smith et al., 1966; Vega et al., 1969) and visual-spatial skills and the performance subtests on the WAIS (Basso et al., 1981; De Renzi et al., 1966; Newcombe, 1974; Reed et al., 1963; Simpson et al., 1971; Smith, 1966; Teuber, 1962; Vega et al., 1969; Warrington et al., 1967) were interpreted as evidence of cerebral dichotomy, although not all the findings supported this notion. Subjects with left hemispheric lesions were more inclined to demonstrate deficiencies on language tasks, while conversely, right brain damage usually resulted in deficits in the execution of visual-perceptual tasks.

A major criticism of these studies, however, is that the majority of researchers used subjects with a wide variety of diagnoses, with varied implications for morbidity and pathology. Often, the possibility for involvement of the contralateral hemisphere could not be excluded (e.g. because of traumatic head injury or neoplasm, Kinsbourne & Hiscock, 1983). Some of the contradictory findings in these earlier studies could also be attributed to small numbers of subjects, subject group differences including age of lesion onset, age at testing, sex and the presence of a seizure disorder (see discussion in Aram, Ekelman, Rose, & Whitaker, 1985).

Furthermore, limited outcome measures were applied, mostly comprising of the subtests of the WAIS. Measures of intelligence have not been found to always reliably predict lesion laterality in adult cases (Dennis & Whitaker, 1977; Kinsbourne et al., 1983). In the acute phase of adult brain injury, the pattern of deficits on IQ tests was found to be related to the side of the lesion, but after the lesion has become chronic, it was not (Dennis, 1985; Fitzhugh, Fitzhugh, & Reitan, 1962).

The subtests of the Wechsler Intelligence Scales have been extensively used to investigate cognitive deficits in unilateral brain damage. Two issues deserve brief attention. Although it has been suggested that the Vocabulary subtest was the clearest measure of verbal abilities and Block Design of spatial abilities (Vega & Parsons, 1969), factor analyses have consistently found that three factors can account for the variance on the WISC-R. These include, verbal communication (Vocabulary, Information, Comprehension, Similarities), perceptual organization (Picture Completion, Picture Arrangement, Object Assembly, Block Design), and factor 3, freedom from distraction (Coding, Arithmetic, Digit Span)(Asarnow, Tanguay, Bott, & Freeman, 1987; Kaufman, 1979). It might be of some benefit to analyze cognitive data using the traditional dichotomous approach (VIQ & PIQ) and this classification.

A criticism levelled at the Performance subtests is that these tests require motor involvement, and right hemiplegics, especially, may be at a disadvantage if they are obligated to use the 'weaker' left hand. Results of other investigations have indicated that impaired sensory-motor performance in the contralateral hand was not related to PIQ, and subjects performed nearly as well using one hand only as they did using both hands (Reed et al., 1963; Vega et al., 1969). Another legitimate concern about the Performance subtests is their strong 'verbal' component (Robinson, 1981; Vega et al., 1969). Deficiencies on these tasks may therefore not necessarily reflect only impairment of visual perception or spatial abilities. In fact, Dennis (1985) points out that factor analysis has identified considerable overlap among the clusters of VIQ and PIQ scales.

(b) Children

It was expected that mechanisms of recovery and reorganization after an unilateral insult to the developing brain would be different to that of the mature adult brain (see discussion in Bishop, 1981). In fact, in one of the few studies of its kind, Teuber et al. (1962), using tilting experiments and tests of visual-perception and body orientation on adults and children, demonstrated that, depending on which test was employed and the age at which a subject was tested, there were marked differences in abilities between the two groups. However, the majority of adults were injured during the Korean campaign, and therefore the cerebral lesions could have been diverse. The intracranial pathology of the children is not discussed at all.

Using children with unilateral brain lesions, researchers investigated the relationship between intelligence and age at walking (Perlstein et al., 1957), the effect of early brain damage on intelligence tests (usually the Wechsler Intelligence Scale for Children-Revised - WISC-R, Alajouanine & Lhermitte, 1965; Kershner & King, 1974; Kiessling, Denckla, & Carlton, 1983; McFie, 1961; Riva & Cazzaniga, 1986; Woods, 1980), performance on visual-spatial tasks (Gersten, Jung, & Brooks, 1972; Wedell, 1960; Wood, 1955), speech and intelligence (Annett, 1973; Rasmussen & Milner, 1977), spoken syntax, language and lexical retrieval (Aram et al., 1985; Aram, Ekelman, & Whitaker, 1986, 1987; Rankin, Aram, & Horwitz, 1981), reading skills (Chadwick, Rutter, Thompson, & Shaffer, 1980), and drawing ability (Kirk & Kertesz, 1989). The results of these studies varied. Some authors were able to replicate the adult studies and show a similar relationship between the side of brain damage and differential cognitive deficit (Gersten et al., 1972; McFie, 1961; Kershner et al., 1974, Kirk et al., 1989), although other studies could not demonstrate any laterality effects (Chadwick et al., 1981; Perlstein et al., 1957; Wedell, 1960; Wood, 1955). In some studies only left hemisphere effects were found (Annett, 1973; Aram et al., 1985, 1986, 1987; Rankin et al., 1981), while others could demonstrate a right hemisphere effect only (Riva et al., 1986; Woods, 1980).

These discrepancies in findings can be explained by limitations of the various study designs (see Kershner et al., 1974; Rankin et al., 1981). In many studies, general intelligence tests were the only measurement employed. These limited the scope of detection of specific deficits. Selection of subjects, and the nature of the intracranial insult were often not controlled, so that the presumed unilaterality of the lesions could not always be substantiated. Furthermore, various studies looked either at language and the defects associated with left-sided lesions, or visual-spatial defects and damage to the right hemisphere but with no within-study control for patterns of defects across groups.

Three major variables that could modify the outcome of laterality research have emerged.

### Sex differences

Sex differences in adults and children have been postulated and confirmed on a limited basis. It would appear that females have a more heterogenous pattern of cerebral speech representation, whereas, in males, cerebral functions are more lateralized (Inglis & Lawson, 1981; Knox & Kimura, 1969; McGlone, 1977, 1978; McGlone & Kertesz, 1973; Shucard, Shucard, Cummins, & Campos, 1981; Witelson, 1976). The possibility of a sex effect on recovery after brain damage in children has not been investigated, but it could be argued that females would be more capable than males to transfer skills to the contralateral intact hemisphere after unilateral brain damage, because a degree of bilateral representation already exists.

Familial sinistrality

It has been suggested that familial sinistrality (the degree to which a subject's first-degree relatives are non-right-handed) might also modify the organization of laterality of higher cerebral functions. The presence of a history of familial sinistrality might be associated with a certain degree of ambilaterality, especially in non-right-handed subjects (Andrews, 1977; Annett, 1973; Hecaen & Sauguet, 1971; Krutsch & McKeever, 1990; Young & Gagnon, 1990), which may be to their advantage in intrahemispheric transfer of lateralized brain functions post unilateral injury.

Neuroplasticity

The last important variable that has to be considered is the age of the subject at onset of the neurological insult. The influence of age of insult had been noted in some studies, although there was no consensus whether early lesions were less or more disruptive than those occurring at a later stage (Alajouanine et al., 1965; Krashen, 1973; Riva et al., 1986; Woods, 1980). The higher potential for recovery in the less mature brain has been attributed to a greater capacity for neuroplasticity (see later). One selection criterion that would insure a uniform cohort would be to include children with congenital hemiplegia only, which would at least limit the onset of the cerebral insult to an intra-utero or intrapartum event.

## (D) Congenital Hemiplegia

The term "congenital" implies that the cerebral insult occurred pre- or perinatally, and the diagnosis is usually clinically obvious in the first year of life (Aicardi, Amsili, & Chevrie, 1969; Kotlarek et al., 1981; Low et al., 1987). Until about 15 years ago congenital spastic hemiplegia was considered to be a perinatal problem mainly caused by brain damage at birth. The proportion of survivors with hemiplegia was found to increase with low birth weight or early gestation (Hagberg & Hagberg, 1984; Powell et al., 1988). Small-for-gestational-age (SGA) survivors were more likely to have hemiplegia than appropriate-for-gestational-age (AGA) infants. Lately, it has been concluded from large epidemiological studies that prenatal influences are likely to be of profound importance as well (see Hagberg et al., 1984; Powell et al., 1988). "Silent" prenatal perfusion insufficiency in the central nervous system, mainly in the third trimester, may possibly be the etiology in congenital hemiplegia of unknown cause (Hagberg et al., 1984). Wigglesworth (1984) has found cerebral changes in infants, who had died at birth, evident of acute anoxic brain damage in utero. The presence of a history of birth asphyxia does not rule out a prenatal insult though. Michaelis, Rooschutz, & Dopfer (1980) argue that newborns with prenatal cerebral lesions are more likely to suffer perinatal asphyxia. Wigglesworth suggests that it might be due to damage to the respiratory center. In a few studies, the variability of the onset of the brain lesion was controlled for by including subjects with a diagnosis of congenital hemiplegia only (Kiessling et al., 1983; Nass et al., 1989; Rankin et al., 1981).

Irrespective of the etiology, patients with hemiplegia are of concern to pediatricians, neurologists, neurosurgeons, educators, neuropsychologists and therapists as far as diagnosis, clinical course, complications, treatment, rehabilitation, education and ultimate prognosis are concerned (Jabbour & Lundervold, 1963). Yet, without an understanding of the major factors affecting the functioning of the central nervous system it would be difficult to identify appropriate intervention (see Fletcher & Satz, 1983). Unfortunately, to quote Alberman and Stanley (1984, p 172), many workers in the field have "reported associations as causal without regard to the problems of selection, bias and the confusing effect of interrelated variables".

The intent of the present study is to focus on one group of brain damaged children, specifically those with congenital hemiplegia. Through the use of parent questionnaires, a physical examination and a comprehensive battery of cognitive and neuropsychological tests, it is hoped to identify specific perceptual deficiencies due to the reorganization of lateralized cerebral functions (namely speech and language skills versus visual-spatial perception) after unilateral brain damage in utero or intrapartum. Special attention will be given to the possibility of the influence of sex differences on the organization of lateralized skills, by analyzing the results for males and females separately. The importance of familial sinistrality on patterns of cognitive recovery will also be considered with the relevant information obtained from a comprehensive family handedness inventory. Results of brain scans and electroencephalograms (EEG) will be noted, and their relation to the psychometric tests examined. The study design will also allow for a control group matched for age, intelligence and parental socioeconomic status to exclude confounding results due to age, mental retardation and family background.

The final objective is to piece together the organization of higher cerebral functions in these exceptional children. This will be achieved in two ways. First, differences between groups (Right and Left hemiplegics and the

Controls) on the outcome measures of the neuropsychological tests will be investigated. Specific defects might indicate differential effects of the side of the brain lesion and possibly confirm the notion of innate cerebral dichotomy. The individual patterns of defects within the different groups would reflect inter- and intrahemispheric reorganization as a function of neuroplasticity. It is hoped that this information will not only have implications for the rehabilitation, education and prognosis of children born with hemiplegia, but that the findings will contribute to the understanding of lateralized cerebral functioning, the role of sex, familial sinistrality and the relative plasticity of the immature brain after an unilateral insult.

# CHAPTER II: LITERATURE REVIEW

From the previous discussion it is clear that higher cerebral functions in children with congenital hemiplegia cannot be examined without taking cognizance of two major theoretical perspectives (lateralization of cerebral function and neuroplasticity) and the variables that influence each of them in turn. The discussion of this chapter will thus focus on a brief overview of these two theoretical perspectives, namely that of lateralization of cerebral function and neuroplasticity.

## I. CEREBRAL DICHOTOMY

### (A) An Historical Overview.

Although the first organized scientific formulation of localization of cerebral function was that of an anatomist, Frans Joseph Gall (1758 - 1828) and his pupil, Johann Caspar Spurzheim (1776 - 1832), the Egyptians seemed to have some notion of the laterality of cerebral function, and Hippocrates wrote about the 'duality' of the brain in about 400 B.C.! Unfortunately, this aspect of Gall's work was ignored when he also argued that the shape of the skull reflects the underlying brain tissue and could therefore be used to evaluate character. The writings of Bouillaud (1864), who first discussed the relationship between the 'leading' hemisphere and handedness, and Jackson (1874) who proposed different functions for the different hemispheres, set the stage for Broca and Dax (1865) to present their evidence for an association between the site of a brain lesion and subsequent aphasia. Later the importance of the side of the lesion was noted. These observations probably constitute the start of the 'cerebral specialization' debate (whether, in fact, cerebral functions are anatomically localized to one or the other hemisphere and if there is an association with 'handedness'), that still rages today in one form or another (for a fascinating account, the reader is referred to the comprehensive reviews of the relevant psycho-medical history in Beaumont, 1974; Rosner, 1974; Springer et al., 1981). Even though Jackson (1865) championed the cause for the right hemisphere as the seat of 'retino-ocular' functions, it was not until the 1930's when standard psychometric tests identified adults with right-sided lesions as having very specific deficits on 'performance tests'. The time had come for the notion of bilateral cerebral participation in cognitive tasks (complementary specialization) to replace the theories of cerebral dominance. It was tentatively agreed that the left hemisphere was superior in dealing with functions relating to language and the right hemisphere with functions requiring visual-spatial skills (see Springer et al., 1981).

### (i) Split-Brain and Hemidecorticate Research

Curiosity as to the functions of the corpus callosum led to extensive testing of patients who had complete or partial commissurotomy (a procedure whereby the neuronal fibers that connect the two hemispheres, of which the corpus callosum is the most prominent, are severed) (Sperry, 1974). What was found was that these patients were unable to verbally identify common objects flashed in the left visual field (the right hemisphere), yet could identify them with the left hand among several objects behind a screen. It also became evident that the left hand was superior at tasks similar to the Block Design subtest on the WISC-R, and drawing three-dimensional figures (Sperry, 1974; and see discussion in Springer et al., 1981).

A modification of this rather radical surgery was developed whereby only the involved hemicortex was surgically removed (hemispherectomy or hemidecortication). This surgery was developed particularly for the removal of cerebral tumors, mostly in adults (Springer et al., 1981) and for the treatment of uncontrolled seizures in children with infantile hemiplegia (Krynauw, 1950; see discussion in Piacentini & Hynd, 1988). The promising initial clinical improvement of cerebral functions after hemispherectomy, had led some authors to optimistically refute any claims of irreversible laterality of cerebral functions (with some reservations), and point out that it seemed possible for either hemisphere to become specialized for the functions of the removed hemisphere (Gott, 1973a, 1973b; McFie, 1961; Smith, 1966a, 1966b, 1969). Adult patients who underwent left hemidecortication did not develop aphasic symptoms and even ended up with higher verbal than non-verbal scores (Smith, 1966). St James-Roberts (1981), in his comprehensive reanalysis of post-hemispherectomy data, points out that in general, these studies lack standardization of design, techniques and measures used. He argues that the results have been confounded by the use of only mentally handicapped patients in some studies or only optimum cases in others, variety of motor handicap, lack of control for memory fluctuations, and fatigue in testing situations. A further methodological limitation in these studies is that measurements of cerebral function have been derived principally from global tests of intelligence (Rankin et al., 1981).

In contrast to these studies, Dennis and co-workers (Dennis & Kohn, 1975; Dennis, Lovett, & Wiegel-Crump, 1981; Dennis & Whitaker, 1976; Kohn & Dennis, 1974) described the language and visual-spatial abilities in some well controlled studies of hemidecorticate children. Subject parameters were well described and lateralized hemispheric functions were extensively examined. Subtle measures of syntax, such as the Active-Passive Test (Dennis & Kohn, 1985), did demonstrate deficiencies in left hemidecorticates. Not only did they show inferior comprehension of passive negative sentences, they generally had significantly longer latencies during testing than right decorticates (Dennis et al., 1975, 1976). Left hemidecorticates were also inferior at using morphophonemic rules to read and spell unfamiliar words (Dennis et al., 1981). In contrast, Kohn et al. (1974) detected that right hemidecorticates were severely impaired on tests of later-developing spatial abilities, like route-finding on a complex map. These children had adequate route-finding skills on simpler tasks (e.g. WISC-Mazes), but they were unable to utilize these fundamental skills in more complex test situations (e.g. Money Road Map Test). Not only do these findings illustrate the lateralization of cerebral functions, but emphasize the importance of using a wide variety of more sophisticated and specific tests to detect deficiencies after hemispheric injury (Kohn et al., 1974, Marozas et al., 1986). It seems that it is not the basic functions that are affected by early hemispherectomy, but the later acquired, more complex functions, whose absence would not have been detected with global IQ tests.

Subjects with congenital callosal agenesis did not prove useful models for the study of cerebral dichotomy. Although they were found to have discrete loss of syntactic-pragmatic function and an inability to identify dichotic speech sounds with overlapping temporal-accoustic properties, they seemed to have anomalous cerebral lateralization of speech and language (Dennis, 1981). The neural basis for these findings are not known. It is possible that the presence of one developmental abnormality would be associated with other less obvious anomalies.

An important caveat in all the research referred to so far, is that in the split-brain research the two hemispheres could not be considered "normal", nor can the remaining hemisphere after hemispherectomy be considered so, as the surgery was usually performed for an uncontrolled seizure disorder or malignancy, an indication that intracranial morbidity was present prior to surgery. In most of the patients with seizures, the disorder had been present for a long time. Usually injury occurred at, or shortly after birth, so that there was ample opportunity for functional re-organization - see later (Kinsbourne et al., 1983; Whitaker & Ojeman, 1977).

In summary, specific deficits related to the side of surgery could be demonstrated in post hemispherectomy patients, but these deficits were subtle, and required measures of complex, later acquired skills. Deficits in language occurred after left hemispheric lesions, visual-spatial skills were generally affected by right cerebral lesions.

### (ii) Research on Patients with Unilateral Brain Damage

Research on patients with unilateral cerebral damage is by its very nature _post facto_, with no control over independent and confounding variables. It is therefore surprising, and somewhat reassuring, that a wide variety of research with marked differences in methodology, subjects, (their inclusion criteria and diagnoses) and the tests used, could still yield findings which in general, reaffirm the outcome of the hemidecorticate studies. Lesions in the left hemisphere lead to deficiencies of verbal tasks, and in the right hemisphere, visual-spatial skills are compromised.

Studies in patients with unilateral brain damage differ from those on hemidecorticates. In the latter group, the damaged hemisphere was removed and research focussed on the ability of the brain to transfer the lateralized functions to the contralateral "intact" hemisphere. In subjects with unilateral brain injury, the damaged hemisphere remains _in situ_. There are therefore several ways perceptual deficits could come about. Rankin et al. (1981) suggested the following mechanisms (Rankin's discussion referred primarily to deficits in language skills):

1. Transfer of function to the contralateral side which is ill-equipped to deal with the task.

2. The function remains in the damaged hemisphere which copes less ably.

3. The presence of the damaged hemisphere interferes with the effective development of contralateral skills in the uninvolved side.

(a) Research that Focussed on Language Abilities

The association of aphasia and lesions of the "dominant" hemisphere was the first sign to alert pathologists to a possible anatomical cause-and-effect relationship. Early research in children concentrated on examining aphasia and patterns of recovery after unilateral brain damage at different ages (Alajouanine et al., 1965; Basser, 1962). Annett (1973) recorded speech difficulty or developmental delay in the acquisition of speech in 40.7% of 59 children with right hemiplegia, and for only 14.9% of 47 children with left hemiplegia. The incidence of misarticulation was also found to be more common in left-lesioned children by Aram et al. (1985).

Verbal and cognitive sequelae after left hemisphere lesions were examined using Wechsler tests (not always exclusively) in children (Kershner et al. 1974; Levine, Huttenlocher, Banish, & Duda, 1987; McFie, 1961; Nass et al., 1989; Riva et al., 1986) and adults (Reed et al., 1963; Vega et al. 1969). The research by Reed et al. and Vega et al. on a variety of adult patients demonstrated a markedly poorer performance on all the Verbal subtests in subjects with left brain damage than right-lesioned subjects, although scores on the PIQ were not significantly different between the two groups. Levine et al. could not demonstrate any main effects of lesion laterality in children, but correlational analyses showed that both Verbal intelligence (VIQ) and Performance intelligence (PIQ) decreased with increasing lesion size. In their study of 48 subjects who had suffered unilateral brain injury before one year of age, Riva et al. found that early left lesions affected VIQ and PIQ equally, whereas lesions after one year did not significantly lower either VIQ or PIQ relative to controls. McFie did find some deficits in left-lesioned children on Digit Span and Similarities, but these were not as striking as in adults, nor did the differences between the side of damage reach statistical significance. An analysis of the data in the study by Kershner et al. showed that right hemiplegics had lower mean VIQs than the non-damaged controls and scored significantly lower on the Arithmetic and Similarities subtests.

Lexical comprehension and production was found to be depressed in both right- and left-lesioned subjects, but left-lesioned subjects were markedly more deficient in tests of syntactic production, simple and complex sentence production, and they had longer latencies on lexical retrieval (Aram et al., 1985, 1986, 1987; Kohn, 1980).

In general terms, these studies found deficiencies on language tests associated with left hemisphere lesions, but some studies found that, when the insult was before one year of age, both verbal and performance scores were depressed. There have also been reports of right hemispheric involvement in speech and language. A delay in onset of speech in childhood due to right hemisphere damage has been described (see Bishop, 1981). Linguistic abilities of the right hemisphere have also been described (Cavalli, De Renzi, Faglioni, & Vitale, 1981; Grossman & Haberman, 1987, Searleman, 1977; Subbash & Orlando, 1983; Villardita, 1987), especially its contribution to the understanding of emotional content, prosody and emotional gesturing (Bowers, Coslett, Bauer, Speedie, & Heilman, 1987; Cohen, Prather, Town, & Hynd, 1990; Ross & Mesulam, 1979; Wapner, Hamby, & Gardner, 1981). Subhash et al. proposed that the right non-dominant language system is anatomically and functionally tied to the dominant left system.

### (b) Studies that Focussed on Visual-Spatial Skills

The association between right hemisphere lesions and visual-perceptual deficiencies has been examined using Wechsler tests on adults (Reed et al., 1963) and children (Kershner et al., 1974; McFie, 1961; Riva et al., 1986; Woods, 1980), and with a wide variety of other tests e.g., visual retention (Warrington et al., 1967), object identification tests (De Renzi & Spinnler, 1966), and figure-ground and perceptual closure tasks (Wedell, 1960; Wood, 1955). In the studies of Kershner et al. and Wood, no significant visual-spatial deficits could be demonstrated, while De Renzi et al., McFie and Wedell each demonstrated deficiencies on some of the tasks. Right-lesioned subjects' performance on spatial tasks, was significantly poorer than left-lesioned subjects on all tasks in reports by Reed et al., Warrington et al., Riva et al. and Woods. Riva et al. also concluded that early and late lesions of the right cerebrum lower the PIQ only, while Woods found that earlier lesions impaired both the VIQ and PIQ, and that lesions after age one impaired Performance ratings only (Woods, 1979).

In their respective studies, McFie (1966) and Newcombe (1974; Newcombe, Ratcliff, & Damasio, 1987) attempted to analyze the deficits based on the anatomical intra-hemispheric locations of the lesions. Newcombe was able to identify some interesting correlations between specific visual-perceptual deficits and lesions at different anatomical sites within the right hemisphere, but in view of the complexities of dichotomy research, the conclusions are probably somewhat premature.

To confuse issues further, some visual-spatial deficits have been demonstrated after left hemispheric lesions, e.g. the Mazes subtest on the WISC (Kershner et al., 1974), Picture Completion, Block Design, Picture Arrangement and Object assembly on the Wechsler-Bellevue Test, and the Raven's Colored Progressive Matrices (Basso et al., 1981) and on a variety of visual-spatial tests (Ogden, 1989). Facial recognition is traditionally considered a right hemispheric task, yet, the recognition of famous faces has been found to be operationalized in the left hemisphere (Marzi & Berlucchi, 1977; and see Benton, Hamsher, Varney, & Spreen, 1983).

Some of the reasons for such variable and often discrepant results have already been discussed in the previous chapter. Suffice it to say that these studies represent a wide range of methodologies, with variable subject inclusion criteria and poor control of incidental variables (see Chadwick et al., 1981). Results of studies investigating visual-spatial functions should also be regarded with some reserve when no attempt was made to differentiate between "pure" visual-perceptual tasks and visuomotor tasks that require a motor response of a physically handicapped subject (see Marozas et al., 1986; Menken et al., 1987; Simpson, 1974) or when subjects with visual defects are included in the analyses (Breakey et al., 1974).

### (c) Studies that Focussed on Congenital Hemiplegia

Finally, let us take a brief look at the three studies that included only subjects with a medical history of congenital hemiplegia. In these studies, many of the confounding variables that have plagued previous research were controlled by strict subject inclusion criteria, similar to the present study. Kiessling et al. (1983), compared eight left and eight right hemiplegics with each other and with 13 sibling controls on a test of manual dexterity and a battery of neuropsychological tests. Retarded subjects (they had to have a verbal IQ as measured on the Peabody Picture Vocabulary Test of 70 or more) were excluded, and there were no differences between the two hemiplegic groups with regard to socioeconomic status or familial sinistrality. These authors were able to demonstrate that the left-lesioned group had subtle deficits in complex language functioning (on Syntactic Awareness and Binet Sentence Repetition Tasks) compared to right-lesioned subjects. Both hemiplegic groups had depressed scores on Digit Span (WISC) and the Boston Test of Confrontation Naming, but the right-lesioned subjects did significantly worse than their controls. Neither the Raven's Matrices nor the Wide Range Achievement Test-Revised (WRAT-R) differentiated between the two pathological groups. One concern with this study is that the low scores some of the subjects achieved on the Annett Pegboard for the uninvolved hand could imply some measure of bilateral cerebral involvement.

Rankin et al. (1981) compared the language abilities of three right and three left hemiplegic children. The unilaterality of their subjects was confirmed by CT scan. One of the left-hemiplegics had also contracted H-influenza meningitis at the age of four and suffered from a congenital cyanotic heart lesion, both of which could have modified her performance so that her results have to be treated with some circumspection. Despite these reservations and the small numbers involved, Rankin et al. was able to demonstrate that right hemiplegics performed less well than left hemiplegics on measures of syntactic comprehension and formulation, semantic comprehension and speech production (using a variety of language tests).

Two hemiplegic groups without mental retardation were compared on Wechsler data in a study by Nass et al. (1989). The difference between the PIQ scores of the two groups was not significant. The left-lesioned group scored superior to the right-lesioned group on the VIQ scores. These rather unexpected findings were interpreted as consistent with the hypothesis of a left-right maturational gradient (Corballis & Morgan, 1978), whereby early right hemispheric damage has a more severe effect on overall intellectual functioning, because the more mature left hemisphere would be less 'plastic' and therefore less likely to participate in the cerebral reorganization.

Two of the studies just described (Kiessling et al., 1983; Rankin et al., 1981) were able to demonstrate some measure of language impairment in subjects with right hemiplegia (left-lesioned). On the other hand, Nass et al (1989) found the opposite. In their study, it was the right lesioned subjects who had inferior scores on VIQ. Their findings will be discussed in more detail later.

In summary, because of individual variation, each patient with suspected asymmetrical brain injury requires careful diagnostic assessment of lateralized cognitive functions to identify strengths and weaknesses. The apparent lateralization of higher functions, language to the left hemisphere and visual-spatial to the right, does not seem an 'all-or-none' phenomenon. Both hemispheres can deal with a wide variety of specialized skills, but perhaps it is the way that information is dealt with, that differentiates them (Springer & et al., 1981).

### (iii) Studying Asymmetries in the Normal Brain

The limitations of research on subjects with brain injury are evident. As already been pointed out, in most of the patients who were studied after split-brain procedure or hemispherectomy, the surgery had been done for an underlying pathological process. In the case of split-brain patients, an uncontrolled seizure disorder had usually been present soon after birth. The result of this is that, not only had the cerebral cortex been exposed to recurrent seizures that could have caused functional disorders in both hemispheres, but, as the underlying pathology had been present since early childhood, some 'reorganization' of lateralized cerebral functions could have taken place. The organization of specific cognitive functions demonstrated in these patients after split-brain procedures thus does not necessarily reflect that of 'normal' brain. Likewise, there were no guaranties that the hemisphere remaining after hemispherectomy had not been affected by the underlying pathology (e.g. malignancy), nor was the extent of cerebral reorganization, prior to surgery, known (see Kinsbourne et al., 1983). The information obtained from these studies, as important and ingenious as they were, could not be applied to normal subjects without reservation. The ideal, then, would be to develop techniques to study the organization of cognitive function in subjects whose cerebral development had not been modified by an underlying pathological process.

### (a) Tachistoscopic Tests

This technique had been developed in patients with split-brain research and modified for use in normal subjects (e.g. Bryden & Rainey, 1963; Geffen, Bradshaw, & Wallace, 1971; Kimura, 1969; Marzi & Berlucchi, 1977; Potter & Graves, 1988). Use is made of the unique properties of the visual system - images that are briefly flashed onto one visual field are exclusively relayed to the contralateral visual cortex (see Hahn, 1987). In this way, each hemisphere receives complete input from the contralateral visual half-field of both eyes. The hemispheres can be investigated separately, by exposing each to verbal and non-verbal stimuli in turn, and monitoring measures such as perception accuracy and latencies. It was hoped that in this way information from 'normal' subjects could be obtained. Three major issues have been identified that complicate the interpretation of the results; the reliability of the task, priming effects and procedural variations associated with stimulus presentation (Hahn, 1987).

There is some concern about the basic assumptions of this research paradigm. Contrary to the situation in split-brain patients, where interhemispheric commissural fibers had been severed, connections are intact in normal subjects. Although the visual image is projected to one hemisphere initially, transfer to the contralateral hemisphere is possible. It has been suggested that the image in the contralateral hemisphere would be of a 'poorer quality' and not interfere with the examination of the original stimulus, but this is speculative (see Springer et al., 1981). A technical constraint of tachistoscopic research is that, in order to avoid rapid eye movements (saccades), and possible bilateral presentation of the stimulus to both visual fields, the stimulus has to be presented very briefly (100 to 200 milliseconds). This limits the complexity of the tasks available for study, and specific asymmetry of cognitive functions may be more difficult to detect, as both hemispheres seem to be able to interpret simple verbal and nonverbal stimuli.

Another concern with the tachistoscope paradigm (as well as dichotic listening tasks, see later), is that it usually underestimates the incidence of left hemisphere speech in right-handers. Studies employing the Wada test (a test using sodium amytal to anaesthetize one hemisphere at a time - see later) indicate that more than 95% of right-handed individuals have left hemisphere speech (Rasmussen & Milner, 1977), yet right-ear and right visual field advantage for language stimuli have only been demonstrated in 75-85% of cases (see Krutsch et al., 1990; Springer et al., 1981). Thus, other factors than cerebral dominance may be at work in tachistoscopic recognition, e.g. individual differences in neural pathways or attentional strategies (see Kinsbourne et al., 1983). Results of these studies have been notoriously difficult to replicate. In fact, even retesting the same subjects does not always produce the same results (Springer et al., 1981).

### (b) Dichotic Listening Tasks

The anatomical structure of the auditory system ensures that each hemisphere receives a greater amount of information from the contralateral ear (see Hahn, 1987). Subjects are asked to identify an auditory stimulus, when in fact, two different stimuli are presented, one to each ear. The stimulus that is perceived will then give an indication which is the 'dominant' ear, implying a language superiority for the contralateral hemisphere. This method has been used especially for investigating laterality of language (e.g. Bertoncini, Morais, Bijeljac-Babic, McAdams, & Mehler, 1989; Geffen, 1976; Hiscock & Hiscock, 1988; Hiscock & Mackay, 1987; Kimura, 1963; Knox & Kimura, 1970; Netley, 1972).

Generally, the evidence from this paradigm has demonstrated a small but consistent right ear advantage in processing verbal stimuli for adults and young children (see Bertoncini et al., 1989; Geffen, 1976, Hahn, 1987; Kinsbourne et al., 1983), but many findings have been difficult to replicate. Factors such as the reliability of the task, the acoustical properties of the stimulus, attention, and memory seem to influence the direction and magnitude of the ear advantage (Hahn, 1987; Kinsbourne et al., 1983). The lack of inter-modal correlation has often been considered evidence for a lack of validity of dichotic and tachistoscopic tasks (Krutsch et al., 1990). If these tests are measuring the same lateralized functions, it would be reasonable to expect them to produce results that are highly correlated. Krutsch et al. point out that one reason for the absence of cross-modal correlation is that 'language' is a multifactorial construct. Another reason could be that usually the two tasks used possessed inadequate reliability, and when the reliability was controlled for, Krutch et al. were able to demonstrate a significant cross-modal correlation.

(c) Dichaptic Tests

Standard behavioral techniques for studying the right hemisphere's role in spatial processing (e.g. tachistoscopic tasks) have proved difficult for young children. In 1976, Witelson devised a test of tactual perception that could be used over a wide range of ages.

Stimuli presented to each hand are conveyed primarily to the contralateral hemisphere, especially fine sensory input to the fingers (see Hahn, 1987). A left hand advantage for identifying forms and dots was interpreted to reflect a right hemisphere specialization for processing tactual-spatial information. Witelson found that the left-hand score of boys was significantly better than the right-hand score, but there was no difference between hands for the girls. She interpreted these findings as proof that males were more lateralized for spatial skills than girls and that this may be so from an early age. Dichotic tests administered to the same subjects were unable to demonstrate a sex difference in ear advantage (also see discussion in Springer et al., 1981). A wide variety of stimuli have been used for tactual exploration, including nonsense shapes, textures (Koenig, 1987), shapes of concrete objects and single letters (see Hahn, 1987). Stimulus variables are probably as important in tactile as in visual and auditory laterality studies, but they are even more difficult to identify and control (Kinsbourne et al., 1983). Although a left hand superiority has been demonstrated for these stimuli, the superiority appears at different ages for the different stimuli. In other words, there are developmental effects (Hahn, 1987).

The results of all three of the research paradigms discussed above, are difficult to interpret. Consensus has not been reached as to whether the size of asymmetry found is an indication of the degree of laterality of the subject (Kinsbourne et al., 1983). The results using language stimuli have been most consistent in showing a right-sided (left hemisphere) advantage in the majority of right handed subjects. Although many non-language stimuli have elicited a left-sided (right hemisphere) advantage, the results have not been as consistent (see Hahn, 1987; Kinsbourne et al., 1983; Krutch et al., 1990; Springer et al., 1981).

### (d) Evoked Potentials

This method of studying brain function, evolved from electroencephalograms (EEG), measures changes in electrical activity in the brain in response to various stimuli. Average evoked potentials are obtained by algebraically summating short portions of the EEG activity time locked with the onset of a stimulus (see Hahn, 1987). Visual (Davis & Wada, 1977), and auditory evoked potentials (Davis et al., 1977; Molfese, Freeman, & Palermo, 1970; Molfese & Molfese, 1979, 1985; Shucard et al., 1981) and the association with the different hemispheres have been the most frequently measured. Hemispheric differences have also been noted when subjects were presented with simple stimuli such as clicks (right hemisphere activation) or blank flashes of light (left hemisphere activation) (Davis et al., 1977). An overview of all studies using this paradigm suggest that lateral differences in the processing of linguistic and nonlinguistic information are present at birth (Hahn, 1987; Kinsbourne et al., 1983). Despite earlier successes in demonstrating lateralization of cerebral function, many later studies failed to replicate these findings, or even showed opposite effects (see Springer et al, 1981). The confusion may be due to the selection of the aspects of electrical activity that were measured, failure to control for individual differences among subjects and the use of tasks that do not differentially involve the two hemispheres. Until many of these technical and methodological issues are resolved, it is probably premature to advocate evoked potentials as a measure of cerebral asymmetry without qualification.

(e) Other Research Paradigms

Various models have also related hemispheric specialization to attention (Kinsbourne, 1970), cognitive style (Seamon & Gazzaniga, 1973), blood flow in the brain (Deutsch, Bourbon, Papanicolaou, & Eisenberg, 1988; Hannay, Falgout, Leli, Katholi, Halsey, & Willis, 1987; Goldenberg, Podreka, Steiner, & Willmes, 1987; Lassen, Ingvar, & Skinhoj, 1978), lateral eye movements (see Gur & Gur, 1980; Kinsbourne et al., 1983), the position of the hand while writing (see Herron, 1980; Hiscock, Hiscock, Benjamins, & Hillman, 1989), directional bias (Alter, Rein, & Toro, 1989) and cerebral metabolism (Plum, Gjedde, & Samson, 1976). Although many of these paradigms have led to interesting speculations, neurobiological measurements such as cerebral blood flow and especially measures of cerebral metabolism, may gain importance in future research, because of the objectivity of the measurements.

### (f) Neuro-Anatomical Findings

The anatomical asymmetry between the hemispheres and its correlation with the functional specialization of the hemispheres have been extensively reviewed (Galaburda, Corsiglia, Rosen, & Sherman, 1987; Galaburda, Rosen, & Sherman, 1990; Geschwind, 1974; Witelson, 1980; but also see Kinsbourne, 1975; Whitaker et al., 1977 for some reservations). The association between functional and anatomical asymmetry remains speculative at best. Geschwind and Levitsky (1968) identified a larger temporal lobe region, known to be crucial for language functions, in the left hemisphere than in the homologous region of the right hemisphere in the majority of cases they examined. Similar right-left differences have been found in studies of adults by Galaburda, LeMay, Kemper, and Geschwind (1978), Galaburda, Sandes, and Geschwind (1978), and in neonates (Witelson & Pallie, 1973). However, some regions of the brain that are part of the speech and language system have been shown to be larger in the right hemisphere than the left (Kinsbourne, 1975; Wada, Clark, & Hamm, 1975; Whitaker et al., 1977).

## (B) Proposed Mechanisms for Laterality of Cortical Function

It is beyond the scope of this paper to review all the proposed mechanisms for cerebral dichotomy in detail (see extensive reviews by Allen, 1983; Beaumont, 1974; Bever, 1975; Hardyck, 1977; Marshall, 1973; Satz & Fletcher, 1981; Semmes, 1968; Whitaker et al., 1977). So briefly, a classification system, elaborated by Allen (1983), will be used as a framework for this discussion. He divides current models into four major groups:

### (i) Unilateral Specialization Model

In 1865, Broca and Dax both argued for the unilateral specialization of language (see Allen, 1983; Beaumont, 1975; Springer et al, 1981). This was also the conclusion of Lenneberg (1967). He held the view that after an early stage of equipotentiality, language became completely lateralized to the left hemisphere. The dichotomous view that each hemisphere is exclusively responsible for a set series of tasks (the all-or-none phenomenon or also referred to as 'invariant hemispheric specialization'; Young, 1990), cannot be supported by current research. Several examples of contralateral hemispheric involvement have already been mentioned before, including recognition of famous faces processed in the left hemisphere and the understanding of emotional content in the right. Still, there are several models that lean heavily on this general all-or-none model.

(a) Speech

Speech and specific components of the speech signal (e.g. voice onset time and speech production) are still considered to be unilaterally represented. Evidence for this comes from data of subjects tested with the intracarotid amytal procedure (Rasmussen et al., 1977). This model does not explain some of the findings in left-handed subjects with familial sinistrality (Hecaen et al., 1971), where anesthetizing one or the other hemisphere did not lead to expressive aphasia.

(b) Motor functions

Lomas and Kimura (1976) have argued that the left hemisphere is unilaterally specialized for some motor functions, in particular those requiring rapid, nonvisually guided movements (e.g. speech).

(c) Serial and temporal functions

This hypothesis states that the left hemisphere processes in a serial fashion (processing time increases with the number of elements to be processed), whereas the right hemisphere processes in a parallel fashion (processing time is independent of the number of elements). Although Cohen (1973) was careful to limit this claim to alphanumeric stimuli, the notion is now firmly entrenched in the literature in a stronger version. It is suggested that the left hemisphere is superior in dealing with language because it copes better with the organizational, syntactic, hierarchic and analytical demands of language. On the other hand, the right hemisphere is superior in the expression of visual-spatial understanding, memory and orientation because of the parallel, synthetic and holistic way it deals with information. Bever (1975, p 261), in his review of the literature argues that this asymmetry is a much more complex phenomenon, and is, among other "shaped by explicit social patterns and artifacts, as well as by implicit patterns of thought".

### (d) Focal versus diffuse representation

Studies of sensory and motor capacities of the hands in brain injured subjects led Semmes (1968) to postulate two contrasting models of neural organization in the left and right hemispheres. In particular, a focal representation of elementary functions in the left hemisphere was said to favor integration of similar units (such as manual skills and speech), and a diffuse representation on the right to lead to integration of dissimilar units (e.g. the multi-modal coordination of various spatial abilities). This hypothesis has seldom been tested directly, but is often quoted to explain research findings. The model does not adequately explain the underlying mechanisms responsible for the organization of cerebral functioning in cases of ambilateral representation of cortical functions; for example, in sinistrals where cognitive functions have been found not to have an asymmetrical distribution (see Hardyck, 1977).

Other models that fall into the unilateral model category include lateralization of decisional systems (Gazzaniga, 1974), some types of complex pitch discrimination of the left hemisphere (Sidtis, 1980), the preferred direction of perceptual scan (Herron, 1957) and a superior left hemisphere sensitivity to differences in rapidly changing acoustic cues (Schwartz & Tallal, 1980).

### (ii) Cooperative Interactive Models

All the rest of the models imply some measure of bilateralization.

### (a) Positive Interaction

This model contends that both hemispheres perform a specific function simultaneously and interact via the corpus callosum. The possibility that the two hemispheres might be performing different subprocesses of the same task is not excluded, nor does it imply an equal contribution from each side. This model has not been advanced frequently because underlying mechanisms of the contributing processes have been difficult to identify (Allen, 1983).

(b) Negative Interaction

This model postulates that both hemispheres have the capacity to perform a given task, but they inhibit each other's function, either unidirectionally or bidirectionally. The best examples of unilateral inhibition come from the language domain (see Allen, 1983). With the increasing evidence of right hemispheric speech functions in normal subjects (Searleman, 1977), this model offers an explanation for the prevention of interhemispheric disruption. In fact, Young (1990), argues that left hemispheric specialization is due to a progressive ability of the left hemisphere to inhibit the right.

The best example of bidirectional, negative interaction is Kinsbourne's model of attention and orientation (Kinsbourne, 1970). Later Kinsbourne (1980) postulated that the brain stem might contribute to the cognitive mode by projecting specific tasks to the relevant hemispheres, and in so doing actively select one or the other hemisphere.

### (iii) Parallel Models

In this model, the two hemispheres are assumed to be operating simultaneously and independently of each other. Several theorists have postulated this model (see Allen, 1983). The most well known model of hemispheric parallelism is that proposed by Dimond (1972). During the early, primary stages of an analytical process, it is suggested that both hemispheres are functioning in a parallel independent manner. Integration and organization of activities will then occur at a later stage in the process. Many aspects of this relatively new model await clarification and verification.

### (iv) Allocation Models

Models in this class hold that both hemispheres have the capacity to perform a given task but that, in normal processing situations, only one does so at a time. Three varieties of allocation models have been described, an input model (the allocation of the processing to the appropriate hemisphere occurs once near the beginning of processing), an output model (the allocation occurs near the end), and a switching model (the allocation of process control is switched back and forth between the hemispheres while processing proceeds). Factors that determine this allocation are the nature of the stimulus, attention, hemispheric 'priming', and subject strategies (Allen 1983, Whitaker et al., 1977).

### (v) Other Models

After the extensive review of the literature on human laterality referred to above, Allen (1983) argues that the only parsimonious explanation for the numerous local models and theoretical formulations on human laterality, is the presence of a finite number of subprocessors which are utilized in the performance of all psychological tasks and functions. It is assumed that these subprocessors differ in their functions and distribution across hemispheres. This theorizing, although intriguing, can only be considered speculative at this time.

An interesting perspective is offered by Blokage (1980, p 134) whose observations of the organization of the human body at cellular level in the first two weeks of gestation, lead him to speculate that "all further elaborations of asymmetric form and function derive at least part of their specification from these early cellular events".

Thirdly, Annett (1991), summarizes her research of handedness and cerebral dominance by emphasizing her view that normal lateral asymmetries of hand and brain depend on chance, or a combination of chance and a genetic factor that induces speech development in the left hemisphere (the right shift factor).

Although it would be more parsimonious to postulate one mode of cerebral functioning for all people, confronted as we are by a host of theories and speculations, Marshall's quote (1973 p 468) of George Eliot seems appropriate: "I say nothing of Mr. -'s theory; if we are to have one regimen for all minds, his seems to me as good as any other!"

### (C) Innate Dichotomy

If cerebral dichotomy does indeed exist, the question arises whether it is present at birth, or whether it develops over time.

In 1962, Basser reported that about half of a group of 72 children with brain injury before the age of 2 began to speak at the usual time, while the other half showed some delay. This result was irrespective of which hemisphere was damaged, suggesting that hemispheric asymmetry for language was not well developed by age 2. Results from a group of children with injuries occurring between the onset of speech and age 10, showed speech disturbances in 85% of cases with left sided damage, but injury to the right side produced disturbances only 45% of the time. In right-handed teenagers and adults, aphasia has rarely been found to follow damage to the right hemisphere. All this evidence led Lenneberg (1967) to conclude that lateralization of function in the brain develops over time, but is complete at puberty. Lenneberg's interpretation has not gone unchallenged (Bishop, 1981; Isaacson, 1975; Kinsbourne, 1975; Robinson, 1981). These authors, among others, have pointed out that the earlier outcomes were suspect because the subjects were of varying ages, severely physically handicapped and often mentally retarded. In addition, bilateral brain damage could not be excluded.

In contrast to the use of clinical studies for the development of lateralization during childhood, evidence in favor of complete lateralization at birth comes from studies utilizing sophisticated research instruments. Using an habituation technique of the sucking reflex, Entus (1971) was able to demonstrate that infants averaging 50 days of age had a "right ear advantage" for speech stimuli. Although other investigators had difficulty replicating these studies (see Springer et al., 1981), a recent study by Bertoncini et al. (1989) was able to demonstrate a stronger reaction to right than left ear changes during dichotic listening tasks in 4-day-old infants using a High-Amplitude-Sucking procedure. Evoked potential studies (Molfese et al., 1970, 1979, 1985) with infants from one week to ten months of age showed responses of greater amplitude over the left hemisphere if "speech" sounds were presented and over the right if "non-speech" sounds (e.g. a piano chord) were presented (but see cautionary note, Kinsbourne, 1980). These results presumably reflect greater involvement in the processing of the sounds. Wada and Davis (1977) were able to demonstrate similar differences in 50 infants ranging from 1 day to 5 days using clicks and flashes.

Anatomical examinations of infants at autopsy showed a larger temporal plane on the left than the right in the majority of cases examined (Vargha-Khadem & Corballis, 1979; Witelson et al., 1973), yet in some cases the opposite has been demonstrated (Wada et al., 1975). In the latter study, females predominated the group in which the right temporal plane was the larger.

The research referred to above, suggests that hemispheric differences are present at birth. However, it should be kept in mind that the measurement of laterality is far from perfect and might be sensitive to factors other than brain lateralization (Hahn, 1987; Kinsbourne, et al., 1983), such as attention or priming. Young (1990) argues that the 'truth' is probably somewhere between the two extremes of innate cerebral dominance and equipotentiality, and suggests that progressive lateralization be considered as an alternative hypothesis. Satz, Strauss, & Whitaker (1990) provide a similar concept of lateralization and link it causally to a multi-dimensional functional maturity of the brain. In this model, cerebral functions are progressively transferred from primary elemental cortical zones that are more mature at birth, to secondary association areas that mature later within the same hemisphere. This approach links well with Goldman's (1972) and Bishop's (1981) notions of competition of later developing cerebral functions for a limited number of synaptic sites (see later).

### (D) Sex Differences

Although no data are yet available concerning sex differences and recovery of early brain damage (Bishop, 1981), the apparent differences in the consequences of unilateral brain damage in adult males and females have alerted researchers to the possibility of sex differences of cerebral lateralization (McGlone, 1977, 1978).

Lansdell (1962) studied adult post-hemispherectomized patients and found an association of skill deficit and side of surgery in males only. He was among the first investigators to speculate that verbal and visual-spatial abilities might be bilateral in females, but may be located in opposite hemispheres in the male brain. McGlone (1977, 1978) reported data from 85 right handed adults (15-70 years) with hemispheric damage either due to a stroke or tumor. She was able to demonstrate that aphasia following damage to the left hemisphere occurred three times more frequently in males than in females. In her study the results of the performance subtests of the Wechsler Adult Intelligence Scales (WAIS) did not show significant effects due to sex or side of lesion, yet the males had larger verbal/non-verbal discrepancies than the females. Left brain damaged males scored significantly lower than right brain damaged males, but left- and right brain damaged females' performance was similar. When comparing visual-spatial skills between the sexes, it was the right-lesioned males that had the greatest deficits on visual-spatial tasks (McGlone & Kertesz, 1973). Blanton & Gouvier (1987) found that adult males required greater lengths of time to locate stimuli in left hemispace after right cerebrovascular accidents, than females. This evidence suggested that male brains are more asymmetrically organized than females. In fact, in a re-analysis of dichotomy research, Inglis et al., (1981) came to the conclusion that some of the contradictions concerning the effects of unilateral brain damage can be explained if the influence of sex is taken into account (but per contra, see Kertesz & Benke, 1989; Kertesz & Sheppard, 1981). Herron (1980) found sex related differences in hemispheric specialization among left-handers, but not right-handers.

Various other research paradigms have suggested that cerebral functions are more asymetrically organized in males, possibly even at birth (Humphrey & Humphrey, 1987). Using dichotic listening tasks, Knox et al. (1970), demonstrated a higher incidence of right ear superiority for discerning speech sounds and left ear superiority for non-speech sounds in males, but not in females. Sex differences have been demonstrated in 3-month-old infants, using auditory evoked responses (Shucard et al., 1981). In dichaptic research (tactual perception), boys had significantly better left hand scores than right hand scores (Witelson, 1976). There was no difference between the hand scores for the girls. Sex differences have been demonstrated with event-related potentials, although the underlying mechanisms were not easily identified (Taylor, Smith, & Iron, 1990). Some studies have also suggested that anatomical differences may exist (Galaburda et al., 1990), although, females who are reported to be less lateralized functionally, have been found to have more asymmetrical anatomical organizations than males (Wada et al., 1975).

After testing 80 normal children, divided into groups based on age, sex and maturational level, on a wide range of standardized and experimental tests, Waber (1976) proposed that sex differences in the lateralization of cerebral functions may not be due to the sex per se, but that they were correlated with maturational rate. Furthermore, Potter & Graves (1988) suggest that females might have better interhemispheric transfer of perceptual information through a larger corpus callosum, and that this may, in part, explain the perceived absence of laterality. These factors could explain the variability in the effects of brain damage within groups of males and females. After an examination of laterality research that used tachistoscopic, dichotic, dichaptic and evoked potential paradigms, Hahn (1987) came to the conclusion that sex effects have not been consistently or satisfactorily demonstrated. Cerebral blood flow studies have not demonstrated sex effects (Deutsch et al., 1988), and a higher degree of lateralization in certain females than males has been shown using dichotic tasks (Hiscock & Hiscock, 1988), and on tasks requiring 'mental rotation' (Casey & Brabeck, 1989).

It would be reasonable to presume that ambilaterality in females would be to their advantage in post-injury interhemispheric transfer of skills. Yet, if the female brain develops more rapidly than the male brain (Yakovlev, 1959, as sited by Bishop, 1981; - this forms the basis of Waber's hypothesis), Bishop points out that the relatively less "committed" male brain would be more capable of reorganization. Males should therefore not develop specific deficits but rather be affected in a wide range of cognitive functions. Kimura (1963) was also able to demonstrate that boys lagged behind girls in development of speech lateralization, by testing 4-year-old boys and girls with dichotically presented spoken digits.

Sex differences in brain development and differentiation of the central nervous system have been demonstrated in higher primates (MacLusky & Naftolin, 1981; Toran-Allerand, 1986). These results lend some credence to findings of innate sexual differentiation of cerebral organization in humans.

### (E) Familial Sinistrality

Early studies have shown that unilateral brain damage in right-handed and non-right-handed subjects had different effects (Gloning, Gloning, Haub, & Quatember, 1969). In the latter subjects, aphasic disturbances were observed in patients with both left and right hemispheric lesions. The non-right-handed patients did not represent a uniform group and there were significant individual differences, but they appeared to have greater ambilaterality of speech representation. Hecaen et al. (1971 p 46) found that this ambilaterality of function was not a characteristic of all left-handers, but 'only of those who belong to the so-called "familial" type'. Left handers have been extensively investigated for differences in cognition (see Gur et al., 1980; Hecaen et al., 1971; Hecaen, De Agostini, & Monzon-Montes, 1981; Harris, 1980; Herron, 1980), representation of speech using the Wada Test (Rasmussen et al., 1977) and anatomical differences (Witelson, 1980). Several different models have been postulated to explain the apparent lack of dichotomy in the non-right-hander (see Andrews, 1977; Beaumont, 1980; Hardyck, 1977; Kinsbourne, 1980; Levy, 1969, 1980).

Considering the controversy in defining 'left-handedness' (Peters, 1990), it is not surprising that the controversy also extends to definitions of familial sinistrality (FS). Hardyck (1977) defined FS as the presence of left-handed preference in at least three members of a biologically related family spanning at least two generations. In their documentation of laterality in left-handers, Hecaen et al. (1971) used a criterion of one parent, sibling or direct descendant who was left handed or at least two other left-handed relatives, e.g. cousins or grandparents. The rationale for some of these definitions is not clear (see

Snyder, 1979). McKeever and VanDeventer (1977) have convincingly argued that basing familial sinistrality designations on first degree relatives alone may result in an inaccurate measure. Andrews (1977) tried to compensate for this by assigning point values and so represent FS as a continuous dimension, even assigning half point values for ambidextrous relatives. In the present study, a numerical system for the classification of subjects according to FS was used as proposed by Snyder (1979). This system was based on the formulation of relationships between parents and their offspring in terms of path coefficients (see later). A similar system was utilized by Young et al. (1990) in their study of the effect of FS on neonatal laterality.

In the case of hemiplegic children, handedness is determined by their physical disability. To quote Annett (1973 p 5): " The best guess that can be made about their (hemiplegic children) potential cerebral laterality, prior to injury, is that the majority would be inclined toward left hemisphere speech, irrespective of familial handedness and that the proportion of cases with potential ambilaterality would be greater in those with familial sinistrality". Few studies in children have considered FS, but a definite effect has been illustrated in language research using a tachistoscope (Andrews, 1977), naming tasks (Krutsch et al., 1990), and in some perceptual tasks (Gilbert, 1977). Familial sinistrality has even been highlighted in the variance in neonatal laterality (head turning) research (Young et al., 1990). An interaction of familial sinistrality with sex has also been demonstrated. Annett (1973) found that left hemiplegic females without FS were more severely affected than those with FS, while all right hemiplegics and left hemiplegic males with FS were more severely physically and intellectually handicapped than those without.

It is clear that the presence of FS could influence the outcome of research into the organization of cerebral functions in congenital hemiplegia, even if handedness is 'pathological', because the ability to switch hemispheres after unilateral brain damage is expected to be superior in subjects with a history of familial sinistrality (Robinson, 1981).

## II NEUROPLASTICITY

### (A) Patho-Physiological Considerations

The apparent resistance of the infant brain to hypoxic damage has been explained on the basis of a decreased metabolic rate secondary to incomplete elaboration of the dendritic complex (Robinson, 1981). Cerebral recovery after mechanically disrupting events in infancy has been attributed to a greater capacity for neuroplasticity. Kolb and Whishaw (1989) define plasticity as morphological changes that occur after brain injury. They described three mechanisms of morphological change, the first being anatomical changes such as the modification of existing synapses by axonal sprouting, regeneration or expansion of dendritic surfaces. The second mechanism is neurochemical adaptive processes, like the ability of existing synapses to modify their activity by increasing transmitter synthesis and release, or by elevating postsynaptic response to the transmitter. Finally, they described metabolic fluctuations in cortical and subcortical activity both ipsilateral and contralateral to cortical lesions (also see Bach-y-Rita, 1990; Molfese et al., 1979). These concepts are not to be confused with sparing, which implies the return of the same behavior that was lost, because of, for example diaschisis (see later) or would have developed, or recovery, which is due to the use of some behavioral strategy to compensate for the original function (Kolb et al., 1989).

Early lesions in young kittens, monkeys, or human infants may have less disruptive effects on performance, and a greater degree of behavioral recovery might be possible than a similar lesion inflicted later life. This has been the principal conclusion from the classical work of Margaret Kennard (see Eidelberg & Stein, 1973; Kolb, 1989; Kolb et al., 1989; Robinson, 1981; Schneider, 1979). There is evidence to suggest that if the immature brain is damaged when it is in a "growth mode" (i.e. when cortical migration is complete and the neurons and the dendrites are beginning to form connections, Herschkowitz, 1988), there is likely to be more compensation (Kolb et al., 1989). The greater recovery and sparing of function in neonates are probably associated with the establishment of axo-neuronal projection patterns closer to normal, than would be the case in later acquired lesions (Goldberger & Murray, 1988). Early cerebral plasticity has been demonstrated in several studies (Eidelberg et al., 1973; Goldman, 1972; Kalil & Reh, 1979, 1982; Kolb, 1989; Kolb et al., 1989; J.T. Wall, 1988), although not without limitations (Finger & Almli, 1985; Goldberger et al., 1988; Taylor, 1984).

Mechanisms of central nervous system (CNS) plasticity have been researched by studying various changes of visual and auditory mapping in owls, somatosensory map changes in vertebrates (Finger et al., 1985; Knudsen & Knudsen, 1982, 1985; Merzenich & Kaas, 1982; Rassmusson, 1982; J.T. Wall, 1988; Wall, Felleman, & Kaas, 1983), and collateral sprouting and rerouting after brain lesions (Finger et al., 1985; Kalil et al., 1979; Kaplan, 1988; Waxman, 1988, and see Murakami, Katsumaru, Maeda, & Tsukahara, 1984). Short and long term mechanisms of recovery have been identified. Short term changes involve changes in synaptic functioning (see Eidelberg et al., 1973; Rassmusson, 1982; J.T. Wall, 1988; P.D. Wall, 1988), but because these changes are not relevant to the reorganization of cerebral functions after unilateral brain damage, will not be discussed.

Long term adaptions may include:

1. Reactive synaptogenesis (the formation of new synapses), possibly through collateral or paraterminal sprouting , to occupy synaptic sites vacated by degenerating axons or dendrites (see Cotman, Gentry, & Steward, 1977; Finger et al., 1985; Ichikawa, 1987, Merzenich et al., 1982; Rassmusson, 1982; Waxman, 1988).

2. Redundancy of parallel pathways serving the same function (Eidelberg et al., 1973; J.T. Wall, 1988). Neuronal death of excess neurons during early brain development is an important organizational event (Herschkowitz, 1988) and could be modified by several intrinsic factors, for example hormonal release (see Galaburda et al., 1987; Young, 1990).

3. Formation of alternate pathways that serve similar, but not the same functions (J.T. Wall, 1988; Waxman, 1988).

4. Regeneration of the lesioned pathway by, for example, long range sprouting (not proven, see Eidelberg et al, 1973; J.T. Wall, 1988).

5. New pathways developing after the initial lesion, for example, by collateral sprouting (possibly the same mechanism as discussed under 1, Foerster, 1982; J.T. Wall, 1988). There may also be rerouting of axons to unusual loci and these connections may lead to dysfunction (see Eidelberg et al., 1973; Finger, 1985; Schneider, 1979).

6. The disappearance of diaschisis. 'Diaschisis' is a controversial concept (J.T. Wall, 1988). Diaschisis involves

restoration of function, a concept developed by Von Monakow (see Smith, 1984), who observed that a lesion has radiating effects beyond its original site, and that these effects gradually resolve. Diaschisis is now used to describe restoration of function by freeing of damaged neural pathways from inhibiting effects of the injury, for example, edema (Fletcher, 1988).

7. Myelin sheath formation was found to be retarded in infants who had suffered severe anoxia (Dambska & Laure-Kamionowska, 1990). This retarded brain maturation suggests another theoretical mechanism for allowing the brain to reorganize after brain injury.

It is understood that the regeneration is limited in scope (see Finger et al., 1985; Goldberger et al., 1988; Kershner et al., 1974; Kinsbourne, et al., 1983; Taylor, 1984), is not always functional or adaptive (Eidelberg et al., 1973; Keirstead, Rasminsley, Vidal-Sonz, & Aguayo, 1988) and might even lead to dysfunction (Eidelberg et al., 1973; Finger et al., 1985), but this potential for recovery poses an interesting prospect of positive outcome after brain lesions (Bach-y-Rita, 1990; Finger et al., 1985).

Goldman (1972) suggests that recovery of an impaired function after damage to a specific area of the brain, will depend on the maturational status of the surrounding undamaged areas (functional heterology). If these areas are immature (uncommitted), they might be capable of modification (see

Eidelberg et al., 1973; Fletcher, 1988, Kinsbourne et al., 1983; Taylor, 1984). This hypothesis implies that, after brain damage, there will be neuronal competition for a limited number of synaptic sites mediating both verbal and nonverbal abilities (Annett, 1964; Bishop, 1981; Levy, 1969). Furthermore, it would be expected that hemispheric functions that emerge through late-developing neuronal connections will be more likely to be absent or affected because no further synaptic sites will be available at the time when these functions should develop (Bishop, 1981). Brain damage in early childhood may, therefore, not necessarily be less severe than in adults. It may differ in quality rather than quantity (Goldman, 1974).

Two other examples of vicarious functioning include 'displacement' (often postulated to explain the transfer of speech from the left hemisphere to the right, Satz & Bullard-Bates, 1981), and 'recruitment' (when adjacent brain areas within the same hemisphere are recruited to subserve a function, see Rourke, Bakker, Fisk, & Strang, 1983; Satz et al., 1990). All these mechanisms could have some implications for recovery of lateralized hemispheric functions in patients with congenital hemiplegia.

### (B) Implications for Cerebral Function

Although laboratory research has identified some mechanisms for plasticity (discussed above), there remain few clinical paradigms to study the reorganization of lateralized cerebral functions except through indirect neuropsychological measures. One experimental design that directly assesses the hemispheric organization of speech, is that of the carotid-amytal procedure developed by Wada and Rasmussen (1960). By anaesthetizing the individual hemispheres separately, a cessation of speech and comprehension in the conscious patient indicates the hemisphere in which language is represented. Important in relation to the present discussion are the findings of Branch, Milner, and Rasmussen, (1964, p 404) that approximately two-thirds of left-handed or ambidextrous patients had right-sided speech representation if the injury was "at birth or in early life". Two-thirds of similar patients had left-sided speech if there was no history of trauma. Rasmussen et al. (1977) found that the side of speech representation is more likely to change when an early lesion also modifies hand preference than when a switch in hand preference does not occur. This would imply that the majority of right hemiplegic children will have right sided speech functions to some degree. It has been argued then that time of onset may play a crucial role in accounting for the type and degree of hemispheric reorganization following left brain injury. Satz et al. (1988, 1990) suggest that focal lesions occurring before 12 months were more often associated with a complete interhemispheric shift of speech and hand preference. Lesions occurring between 12 and 72 months were more likely to result in an interhemispheric shift in speech alone, a bilateral or incomplete hemispheric organization, or an intrahemispheric mode of reorganization, without affecting hand preference. It would not seem unreasonable to predict that in subjects with right congenital hemiplegia, a right hemispheric transfer of speech and language functions might occur. This in turn could lead to a disturbance of the right hemispheric organization of visual-spatial skills. On neuropsychological testing, right hemiplegic children might even present with deficits in visual-spatial rather than verbal skills. However, an interference of left hemisphere functions due to interhemispheric reorganization after right-sided lesions has not been found in hemiplegia research. Unfortunately no test similar to the Wada test has been developed for visual-spatial skills; the fate of their organization after right hemispheric lesions remains unclear.

It is obvious, especially in the light of innate cerebral dichotomy, that neuroplasticity is a complicated concept. Wigglesworth (1984 p 24) summarizes the interaction between focal brain damage and processes of normal brain development as follows: "The eventual effect of any lesions on the developing brain will depend on the nature of its interaction with the normal processes of brain growth. In visualizing how hemorrhagic and ischemic lesions in the perinatal brain may interact with the normal developmental processes, it is important to consider the time at which the damage occurred. .....(It) involves a mass of tissue in which synaptic connections are rudimentary, myelination has not commenced and many of the cells may be destined to die. In such a case there may be very considerable capacity for remodelling during later development."

In summary, research from a variety of perspectives suggest that some reorganization of asymmetrical hemispheric skills in children with congenital hemiplegia may occur after the cerebral insult. Research concerning this organization in right and left hemiplegics could shed light, not only on the role of innate dichotomy, but on its modification by neuroplasticity after early brain injury. In the present study, organization and deficiencies of lateralized cerebral functions in children with congenital hemiplegia will be described. Strict inclusion criteria assure an homogenous experimental population to increase the internal validity of the study. Specific psychometric and neuropsychological tests are used to assess the intelligence quotient (Wechsler Intelligence Scale for Children Revised, WISC-R), to test visual-spatial skills (Raven's Progressive Matrices, Benton Facial Recognition and Judgement of Line Orientation Tests, Motor-free Visual-Perceptual Test and the Money Road Map Test) and verbal skills (Peabody Picture Vocabulary Test, Clinical Evaluation of Language Fundamentals, and The Active-Passive

Test). The results of these tests are related to the sex of the subjects, the side of the lesion, the presence of familial sinistrality, and the severity of the motor handicap.

Based on the notion of cerebral dichotomy, it is anticipated that RHP would perform more poorly on measures of language than LHP, while the LHP would have marked deficits on visual-spatial tasks, as compared to RHP, and that sex and the presence of familial sinistrality could modify the outcome.

# CHAPTER III: METHOD

## (A) Design

This is a multi-method (parental questionnaires, neurological examination, neuropsychological assessments) cross-sectional study comparing three groups of children, (right hemiplegics (RHP), left hemiplegics (LHP) and controls (C)) matched on predetermined criteria (age, sex and full scale IQ), on a variety of medical and psychometric measures. In addition, within the group of hemiplegic children, psychometric measures are related to sex, familial sinistrality, side of the lesion and severity of brain damage.

## (B) Subjects

Patients with congenital hemiplegia were identified by chart review at Alberta's two major referral hospitals for cerebral palsy, The Glenrose Rehabilitation Hospital in Edmonton that serves Central and Northern Alberta, and the Alberta Children's Hospital in Calgary, providing services in the South. In addition, a letter was sent to all the peripheral Health Units, explaining the purpose of the study and describing the inclusion criteria, in case any child with congenital hemiplegia in the province had not been contacted. Eighty-six potential subjects were identified.

Table 1

Recruitment of Subjects and Exclusions

| | Right hemiplegia | | | Left hemiplegia | | |
|---|---|---|---|---|---|---|
| | Male | Female | Total | Male | Female | Total |
| Included in present study (n) | 14 | 14 | 28 | 15 | 8 | 23 |
| Excluded (n) | | | | | | |
| 1. Parents refused | 4 | 5 | 9 | 2 | 1 | 3 |
| 2. Could not be traced | 7 | 3 | 10 | 3 | 2 | 5 |
| 3. Home language not English | 2 | 0 | 2 | 0 | 0 | 0 |
| 4. IQ below 60 | 2 | 2 | 4 | 0 | 0 | 0 |
| 5. Testing abandoned | 0 | 0 | 0 | 0 | 1 | 1 |
| 6. Bilateral hemispheric involvement | 0 | 0 | 0 | 0 | 1 | 1 |
| Total | 29 | 24 | 53 | 20 | 13 | 33 |

### (i) Initial Inclusion Criteria

Initial inclusion criteria were identified as follows:

1. Age 6 to 16 years - This decision was made in order to capture as wide an age sample possible who could be tested on the same standardized tests.

2. No obvious mental retardation.

3. Diagnosis suspected before 18 months of age and no other possible cause for the brain lesion suspected than prenatal or intrapartum events.

4. No severe sensory loss (visual or auditory).

5. No obvious involvement of the normal side.

6. Institutionalized and severely socioeconomic and academic deprived children were excluded.

7. Home language had to be English.

### (ii) Initial Assessment

Eighty-six subjects were considered for possible inclusion in this study (Table 1). Twelve parents did not give consent, and 15 subjects could not be traced or had moved to another province. After discussing the research project with the parents four more subjects were excluded, two were too low functioning, and two households did not speak English. Thus 55 subjects were tested.

An appointment was made for the subjects and their parents after parental consent was obtained (also consent o the subjects when older than 12 years of age). At that time, a full medical and neurological examination was carried out by a developmental pediatrician (AV). Specifically assessed were:

1. Height, weight and head circumference.

2. Cranial nerves.

3. Muscle tone, both active and passive as shown by posture, mobility and tendon reflexes.

4. The absence or presence of clonus, tremors, ataxia (or other cerebellar signs), chorio-athetosis, contractures, muscle wasting, and limb shortening was documented.

5. Visual acuity (screening test only).

6. Hearing, by a pure tone audiometric screening evaluation at 25 dB for 500, 1000, 2000, and 4000 Hz bilaterally using an AudioScope 3 (Welch Allyn - registered trademark).

7. Hand function, as assessed by using the Trites Grooved Pegboard for the 'uninvolved' hand, and severity of the hemiparesis by grading the function of the affected hand. Subjects were asked to pick up a peg of the Trites Grooved Pegboard with the affected hand, and given one of the following scores (described in Levine et al., 1985):

1 = Able to grasp with thumb-forefinger
2 = Able to grasp with whole hand
3 = Unable to grasp

8. A cluster of dysmorphic signs suggesting a

recognizable syndrome.

After this examination was completed a WISC-R was administered. At this point subjects were excluded if they:

1. Had not obtained a VIQ or a PIQ over 60.
2. Had severe sensory loss.
3. Had signs of bilateral neurological disease.
4. Had signs suggesting the presence of a clinical syndrome.
5. Had a seizure disorder that could not be medically controlled (an incidence of less than one attack in three months, and no more than two medications required for control).

Of the 55 remaining subjects, another 4 were excluded. Two subjects were excluded because their performance on the WISC-R did not meet inclusion criteria. In one case there were clinical signs of bilateral brain involvement, and in another the testing was abandoned because it was too stressful for the child and she could not stop crying.

The remaining 51 subjects included 28 right hemiplegic children (14 males and 14 females), and 23 left hemiplegics (15 males and 8 females). One LHP male had poor vision in his left eye (< 25/20) even with glasses. A LHP female had a history of optic atrophy and her vision was difficult to assess. She was attending school in a regular classroom, and her standard score on the WISC-R Picture

Completion (which requires subtle visual discrimination) was nine. It was decided to include both of these subjects in further analyses.

### (iii) Further Testing

The subjects ($n$ = 51) that met all these inclusion criteria received further individual testing using a battery of cognitive and neuropsychological tests. All tests were administered by one examiner (AV) who had been trained to use and interpret these tests by various specialists. The tests will be discussed individually later. In cases where children became fatigued, the testing was abandoned and was resumed at the discretion of, and in consultation with the parents. Between one to three sessions were needed depending on the child's age and comprehension.

### (C) Controls

A modified control group was selected to match the distribution of the two hemiplegic groups on age and full scale IQ on the WISC-R. This was not a yoked control group, but rather a group of children without any signs of motor involvement, selected to resemble the subject groups on age, full scale IQ and of parents with similar social class. The need for such a comparison group is to control for low IQ in the absence of cerebral palsy. Differences between groups will represent real deficiencies rather than reflecting poor performance due to intellectual impairment or social experience, a consideration not often taken into account in previous research. The control group had to meet all the inclusion criteria of the subjects.

Thirty children were included in the control group (15 males and 15 females). The children were recruited from five schools in Edmonton, after permission was granted by the Edmonton School Board, to represent a local cross-section of the socioeconomic strata. In order to select one group of children who could serve as a control for both the hemiplegic groups, outlyers (on age and IQ) in both groups were matched first. The rest of the Controls were selected to resemble the respective means. One male was deaf in one ear, but had no abnormalities in the other, and he was included in all analyses. The same questionnaires as those given to the experimental group, were completed by the parents of these children, after parental consent was obtained. The same battery of tests were administered to the controls, but a neurological examination was not performed. Birth and medical records were not assessed.

## (D) Measures

### (i) Parent Questionnaire

Using a parent questionnaire designed for this study, a detailed pregnancy and birth history was obtained, usually from the mother (see Appendix). A neurological history was included and special attention was given to seizures and developmental milestones. In all analyses, walking after the age of two years was considered 'developmental delay'. This criterion was chosen after it became clear that 'age at walking' seemed to be the one milestone parents remembered best (Bradburn, Rips, & Shevell, 1987). There were also specific questions about general medical problems, education and related school problems of the subject, as well as questions concerning the education and occupations of the parents, and family income. Birth and medical records were also reviewed. Four hemiplegic subjects (2 RHP males, one LHP male and one LHP female), and two Controls (one male and one female), did not live with their biological parents, as they had been adopted. The birth and some of the developmental histories of these children were therefore not always available.

### (ii) CT Scans (Brain Scans)

The original tests or the results of CT brain scans were traced, examined and documented for 30 children. No Controls had a brain scan at any time. Two classifications were used to analyze the CT scan data. The first was based on a classification described by Cohen et al. (1981), which grades the severity of brain injury, as demonstrated on CT scan, into seven categories. In the present study there was a paucity of cases in the higher grades, probably reflecting the IQ inclusion criteria. More severe intracranial pathology may have been eliminated a priori.

Because of the small numbers involved, a more parsimonious classification, described by Kotlarek et al. (1981) was also employed:

Grade 1: Normal

Grade 2: Unilateral ventricular enlargement

Grade 3: Cavity in the cortex and/or in the subcortical white matter

### (iii) Electroencephalograms (EEG)

The results of EEGs were traced, examined and documented for 26 children. These results were divided into three groups after a classification described by Cohen et al. (1981), normal, paroxysmal and asymmetrical. Where more than one EEG were reported the most recent was classified. If an EEG showed both paroxysmal and asymmetrical changes, the result was classified as paroxysmal.

### (iv) Socioeconomic Index

The Blishen Socioeconomic Index for the total Canadian labor force, based on the 1981 Census data (Blishen, Carroll, & Moore, 1987), was used to assess the socioeconomic status of all the families, based on information from the parent questionnaires.

### (v) Familial Sinistrality

Parents completed the Edinburgh Handedness Inventory (Oldfield, 1971). This is an inventory containing 10 items (modified by Snyder, 1979) instead of the original 20, which assesses parental handedness during a variety of daily tasks. Although this inventory has been used extensively in handedness research, it has come under some criticism because of the arbitrary equal weights assigned to the various items, even when the motor tasks are not equally complex (Blokage, 1980). A questionnaire inquiring after the handedness of the extended family (grandparents, uncles, aunts, siblings and cousins of the subjects), was also completed. A subject's familial sinistrality score was then computed by assigning the following point values for each left-handed relative (or half these values for mixed-handed relatives) and summing these values: parents and/or siblings, 2; grandparents, uncles and/or aunts, 1; and first cousins, 0.5. In the present study all the left-handed subjects were considered 'pathological', and their scores were excluded. Familial sinistrality (FS) was not computed when information was incomplete. A score equal to 3 or more would be considered evidence for familial sinistrality.

### (vi) Quantification of Treatment

It would seem appropriate that if cerebral reorganization after brain injury is investigated, the effect of 'treatment' should be taken into consideration (Satz & Fletcher, 1981). The numerical presentation of this variable is complicated and no examples are discussed in current hemiplegic literature. In this study, a treatment variable was computed as follows: The duration of treatment by a physical therapist, occupational therapist and a speech therapist was used. Therapy that began shortly after birth and continued till age 2, or part thereof, was allocated a numerical value of 1 for each of the therapies. A further point was added for each of these therapies that continued up to age 5, and another if a subject received therapy after the age of 5. The total 'treatment' score was the summation of all the points, nine being the maximum. Any therapy that was temporarily administered for a year or more, was also allocated one point. The rationale for this classification is based on the organization of special services at the Glenrose Rehabilitation Hospital.

## (E) Tests

Tests were chosen because they were assumed to be sensitive to the influence of brain injury. The decision as to which tests to use was based on results of previous research in this field, as well as the recommendations of Dennis (Dennis, 1988; Dennis et al., 1975, 1985; Kohn et al., 1974), Fletcher (1988), Goldstein (1974), Guthrie (1973), and Taylor (1988). In all cases the Trites Grooved Pegboard and the WISC-R were administered first, and the Wide Range Achievement Test last. The other tests were given in random order alternating between language and visual-spatial tasks.

### (i) General Achievement Tests

(a) The Wechsler Intelligence Scale for Children - Revised (WISC-R, Wechsler, 1974)

The full scale IQ of this test was used as the standard intelligence test because the norms, reliability and validity are well standardized (Sattler, 1988). The Verbal and Performance scales were used separately to analyze lateralized hemispheric skills. The Wechsler data were also analyzed using the 'Kaufman' classification.

(b) Wide Range Achievement Test - Revised (WRAT-R, Jastak & Wilkinson, 1984)

This is a brief norm-referenced test for screening individual reading, spelling and arithmetic skills (Guthrie, 1973). The Reading section tests for word recognition only (Rourke & Finlayson, 1978). With some reservations the reliability and validity are satisfactory (Sattler, 1988).

## (ii) Tests for Verbal Skills

### (a) Peabody Picture Vocabulary Test - Revised (PPVT, Dunn & Dunn, 1981)

This non-verbal, multiple choice test measures receptive vocabulary without requiring a motor response. It is useful as a screening test, especially for children with difficulties with expressive speech. The reliability and the validity are satisfactory (Sattler, 1988).

### (b) Active - Passive Test (A-P Test, Dennis et al., 1985)

The Active-Passive Test measures the ability to discriminate the meaning of spoken statements varying in syntactic form. Six sentences are read in four voices: active affirmative, active negative, passive affirmative and passive negative, and subjects are required to select one of two pictures depicting the relationship. This test has been sensitive in demonstrating difficulties with syntax in left hemidecorticate subjects (Dennis et al., 1975, 1976). Information on validity and reliability is limited, but some quartile ranks for individual scores according to age and age normed z-scores are available.

### (c) Clinical Evaluation of Language Fundamentals - Revised (CELF-R, Semel, Wiig, Secord, & Sabers, 1987)

This test provides differentiated measures of selected language functions in the areas of phonology, syntax, semantics, memory, word finding and retrieval. Standardized scores of six subtests are added to provide a score for expressive and receptive language respectively, the sum of which provides a total language score. Generally, both the reliability and validity have been proven satisfactorily.

### (iii) Visual-Spatial Tests

(a) The Raven's Progressive Matrices (Raven, 1938, 1960, 1965)

The Raven's Matrices make demands on visual-spatial as well as general intellectual abilities (De Renzi et al., 1966). They are considered a test of non-verbal reasoning ability (Kiessling et al., 1983). The task is to find a figure among some alternatives logically completing a picture. The test requires a minimum of verbal and motor skills and is useful for individuals with speech or motor handicaps (Cronholm et al., 1968). The reliability and validity are satisfactory and the test is useful as a supplementary measure of intelligence (Sattler, 1988).

(b) Developmental Test of Visual Motor Integration (VMI, Beery, 1982)

This is a short test that is useful in evaluating visual-motor abilities by requiring the subjects to copy geometric figures that are increasingly more complex.

Reliability and validity, based on the 1964 norms, are satisfactory, although the test was renormed in 1981 (Sattler, 1988).

### (c) Benton Facial Recognition Test (Benton et al. 1983)

In this test a standardized objective procedure for assessing the capacity to identify and discriminate black and white photographs of unfamiliar faces is applied. It is a multiple choice test and errors are noted. The final score is compared to standardized scores for normal, borderline, moderately and severely impaired performance. Although some norms for this test exist, information on standardization and concurrent validity is limited. Because the age at testing was controlled for in this study it was decided to use the raw scores for comparison.

### (d) Judgement of Line Orientation, Form H (Benton et al., 1983)

On *a priori* grounds, this test would seem to be as pure a measure of one aspect of spatial thinking as can be conceived (Benton et al., 1983). Cerebral blood flow studies have confirmed a greater right (than left) hemisphere involvement (Deutsch et al., 1988; Hannay et al., 1987). This is a multiple choice test in which the subject is asked to match lines in various degrees of rotation with a scale of eleven lines in a fan-like presentation. A low partial correlational coefficient with facial recognition was found, indicating that these two tests do not represent similar processes. Limited information is available on standardization and concurrent validity. Although some normative data are available, it is not comprehensive enough to evaluate the performance of children satisfactory. For the purposes of the present study the raw scores will be used in analyses as the groups have similar mean ages.

### (e) The Motor-Free Visual - Perception Test (MVPT, Colarusso & Hammill, 1972)

The MVPT is a test of visual perception which does not require manual manipulation. It is a multiple-choice test based on five theoretical constructs; spatial relationships, visual and figure-ground discrimination, visual closure and visual memory. Progressive degrees of motor impairment have not been found to affect MPVT scores but did affect other visual-motor tasks (Newcomer & Hammill, 1973; Menken et al., 1987). Validity and reliability have been shown to be satisfactory by the developers of this test.

### (f) Money Road Map (Money, 1965)

Subjects are required to state at each of 32 turns on a path drawn through a map, whether they would turn to their left or their right to continue. Neither the map nor the subjects body can be rotated during the task. Orientation for right and left, simultaneously with coming and going in space (a skill that evolves after 7 years of age), is assessed. This test of bodily orientation is one of the few tests found to distinguish right hemispherectomy subjects from left (Kohn et al., 1974). The validity and reliability are not well described.

## (F) Statistics

The relevant statistical manipulations are referred to in each specific section in the next chapter. In general all cognitive and perceptual data were subjected to a 3(RHP, LHP, C) by 2(sex) two-way Multiple Analysis of Variance (MANOVA) to demonstrate any main effects for these two class variables (diagnosis and sex) and their interaction. In all cases the Tukey's Studentized Range (HSD) Test was used for post hoc analysis. The cognitive and perceptual data were also subjected to three-way MANOVAS. A series of third class variables, including; age, seizures and extent of brain damage was entered together with diagnosis and sex. The majority of these analyses were repeated using only the two hemiplegic groups as some of the data were either not available for, or not relevant to, the Controls. Univariate analyses were executed, using the same class variables, on all the cognitive data to identify any interactions with specific cognitive or perceptual variables.

A stepwise regression analysis procedure was used to examine the multivariate associations of the significant independent variables (diagnosis, age, sex, familial sinistrality , hand function, CT scan grade, the presence of problems during pregnancy, birth asphyxia, gestational age, birth weight, the presence of seizures, socioeconomic status, treatment and developmental delay), using the various cognitive tests as outcome measures. Regression analyses were also used to examine the association of the above mentioned variables as well as the cognitive tests outcome measures and the standardized scores of the Reading, Spelling and Mathematics subtests on the Wide Range Achievement Test-Revised.

All nonparametric data were analyzed using Chi square statistics. In order to assess within group differences on the various cognitive and perceptual outcome measures, the three groups were divided at the mean on these measures, and Chi squares were carried out.

# CHAPTER IV: RESULTS

## (A) Description of Subjects - Preliminary Analyses

The relevant descriptive data of the three groups, the right hemiplegics (RHP), the left hemiplegics (LHP) and the control group (C), are summarized in Table 2. The three groups were similar in height, weight, head circumference, social status and age. Overall, the boys were younger than the girls, males being 9.5 years old (SD 1.9) and the females 10.8 years (SD 2.7); this difference was significant ($F1,78$) = 4.85, $p < .05$). However, there was no significant sex by diagnosis interaction.

### (i) Pregnancy and Birth History

In the present study, 26% (7 of 27) RHP subjects had a gestational age of less than 38 weeks (2 at 34 weeks or less). Forty five percent (10 of 22) LHP were born before 38 weeks (7 at 34 weeks or less) and 23% in the control group (5 of 22). None of the Controls had a gestational age under 34 weeks. The number of infants with birth weights under 1250g was four, three, and zero for RHP, LHP and C respectively. There was a main effect of diagnosis for birthweight ($F(2,70) = 4.08$, $p < .03$) and mean gestational age ($F(2,60) = 2.93$, $p = .05$). *Post hoc* analysis revealed that in each case significance at a .05 level was reached between the LHP and Controls only. The percentile rank for birth weight (based

Table 2

Descriptive Data

| | Right hemiplegics (RHP) n=28 | Left hemiplegics (LHP) n=23 | Controls (C) n=30 | Statistics |
|---|---|---|---|---|
| Age at testing in years | 10.2* | 10.0 | 10.2 | ns |
| SD | 2.2 | 2.6 | 2.4 | |
| Weight | | | | |
| In kilograms | 33.0 | 34.3 | 35.0 | ns |
| SD | 8.3 | 12.6 | 11.6 | |
| Percentiles | 50.1 | 50.5 | 51.3 | ns |
| SD | 28.5 | 28.6 | 25.8 | |
| Height | | | | |
| In centimeters | 139.1 | 138.3 | 141.2 | ns |
| SD | 12.5 | 16.6 | 14.1 | |
| Percentiles | 50.8 | 58.7 | 63.3 | ns |
| SD | 26.1 | 29.7 | 25.3 | |
| Head circumference | | | | |
| In centimeters | 52.5 | 52.6 | 52.8 | ns |
| SD | 2.1 | 1.9 | 1.8 | |
| Percentiles | 48.5 | 46.6 | 50.5 | ns |
| SD | 29.0 | 25.7 | 26.9 | |
| Socioeconomic status | | | | |
| Blishen** scale | 41.6 | 41.4 | 41.4 | ns |
| SD | 12.8 | 11.6 | 13.0 | |

*All values reported as means and standard deviations.

**Blishen, Carroll, & Moore (1987)

Table 3

Pregnancy and Birth History

| | Right hemiplegics (RHP) n=28 | Left hemiplegics (LHP) n=23 | Controls (C) n=30 | Statistics |
|---|---|---|---|---|
| Birthweight | | | | |
| In grams | | | | |
| Mean | 2946.6 | 2849.9* | 3494.0* | *p<.05 |
| SD | 964.1 | 1067.8 | 512.3 | |
| Percentiles | | | | |
| Mean | 45.3 | 50.0 | 58.7 | ns |
| SD | 30.7 | 31.6 | 28.6 | |
| Gestational age in weeks | | | | |
| Mean | 38.1 | 36.5* | 39.5* | *p<.05 |
| SD | 4.9 | 4.8 | 2.2 | |
| Frequency of prenatal problems | | | | ns |
| Bleeding in first trimester | 2 | 3 | 1 | |
| Accident/injury | 2 | 1 | -- | |
| Hypertensive disease of pregnancy | 2 | 1 | 1 | |
| Hyperemesis gravidarum | 1 | 1 | 1 | |
| Other | 4 | 2 | 2 | |
| Delivery (n) | | | | ns |
| Vaginal | 17 | 13 | 17 | |
| Caesarian section | 6 | 7 | 3 | |
| Forceps | 2 | 1 | 5 | |
| Twins | 1 | 1 | 1 | |
| Breech | 1 | 1 | -- | |
| Asphyxia diagnosed at birth | 15* | 11* | -- | *ns |
| (n) | (27) | (23) | -- | |
| Apgar at birth | 6.3 | 6.0 | -- | ns |
| SD | 2.2 | 2.5 | -- | |
| (n) | (22) | (26) | -- | |

on percentile charts compiled from statistics in Alberta), gives some indication of the SGA-status of the newborns. The birth weights for 7 RHP, 5 LHP and 1 C were at or below the 10th percentile. These differences were not significant.

The spectrum of concerns during pregnancy is summarized in Table 3. The incidence of problems during pregnancy did not differ significantly over the three groups, but the gravity and implications of the various diagnoses may not necessarily be comparable.

The hemiplegic groups had a higher, but non-significant, prevalence of cesarian sections than the control group. A diagnosis of birth asphyxia was made in about half the hemiplegic subjects (as described in medical records), and only one in four of the Controls (parental report). The higher prevalence of birth asphyxia in the subjects is reflected in the mean Apgar scores at birth, 6.3 (SD 2.2) for the RHP, and 6.0 (SD 2.5) for the LHP. As parent questionnaires were the only source of birth history in the Controls, not enough Apgar scores were reported for a meaningful interpretation and statistical comparison. There was no statistical difference between the two hemiplegic groups on Apgar scores at birth or the prevalence of asphyxia.

Of all the hemiplegic children, 9 had a history of concerns during pregnancy but no birth asphyxia. Fifteen had a history of birth asphyxia only, and 10 had both. The remaining 11, 20%, (information was not available for 6) did not present any obvious perinatal problems. Thus, 39% of the hemiplegic subjects did not have discernible difficulty at delivery.

**The three groups (RHP, LHP and Controls) were similar in weight, height, skull circumference, age, social background, incidence of problems during pregnancy and mode of delivery. The females were generally older than the males, but there were no differences in mean age by sex, or total mean age, between groups. The LHP were significantly smaller and more premature at birth than the Controls, with RHP in the middle. The prevalence of birth asphyxia was similar for the two hemiplegic groups, but significantly higher than in the control group. Twenty percent (11) of the hemiplegic children had no obvious perinatal complications.**

### (ii) Severity of Brain Injury

Indicators of the severity of the brain injury are given in Table 4. As per definition a diagnosis of congenital hemiplegia was entertained within the first year of life, and confirmed soon after the first birthday in both hemiplegic groups. Early hand fisting or preference were usually the first indications of unilateral brain damage. The rating of the affected hand, as suggested by Levine et al. (1987), was discussed in the previous chapter, and the two hemiplegic

Table 4

Neurodevelopmental Data

| | Right hemiplegics (RHP) n=28 | Left hemiplegics (LHP) n=23 | Controls (C) n=30 | Statistics |
|---|---|---|---|---|
| Age hemiplegia suspected in months | 10** | 8.1 | -- | ns |
| SD | 6.6 | 6.8 | | |
| Age hemiplegia diagnosed in months | 13.1 | 14 | -- | ns |
| SD | 7.2 | 8.1 | | |
| Seizures | | | | $p<.05$ |
| Ever | 14* | 11* | 1 | overall |
| Present | 9* | 4* | 0 | *ns |
| Medication | 7 | 4 | 0 | |
| Graded function of affected hand | 2.2* | 2.4* | 1.0 | $p<.05$<br>overall |
| SD | 0.9 | 0.8 | 0 | *ns |
| Function of dominant hand z-score | 0.32 | 0.35 | 0.9 | ns |
| SD | 1.3 | 1.3 | 1.1 | |
| Age at walking in months | 18.6* | 19.9* | 11.2 | $p<.05$ |
| SD | 9.0 | 6.8 | 1.7 | *ns |
| (n) | (26) | (20) | (23) | |
| Age: first words in months | 16.0 | 16.1 | 12.5 | ns |
| SD | 8.5 | 7.4 | 6.0 | |
| (n) | (19) | (14) | (17) | |
| Age: sentences in months | 24.5 | 30.0 | 24.1 | ns |
| SD | 10.9 | 10.6 | 6.8 | |
| (n) | (21) | (12) | (12) | |

****All values reported as means, except seizures, which are reported as frequencies.**

groups did not differ significantly on this rating. Although hand function of the dominant hand, as assessed by the Trites Grooved Pegboard was poorer for the RHP and LHP groups than for the Controls, the differences were not significant.

Fourteen (50%) of the RHP had ever had a seizure disorder, nine were considered to still have seizures and seven were controlled on one medication (the other two were not being treated). Similarly, half (11) of the LHP had ever had a convulsion, and four were still receiving medication (one girl requires two anticonvulsants for medical control). Of the controls, one male had neonatal seizures, but none since. The prevalence of seizures was significantly greater in the hemiplegic groups as compared to the Controls at any age ($\underline{X}^2 = 18.1$, $\underline{df} = 2$, $\underline{p} < .05$), or at present ($\underline{X}^2 = 11.14$, $\underline{df} = 2$, $\underline{p} < .05$), but in the two diagnostic groups the prevalence was similar. Seizures were significantly correlated with birth asphyxia ($\underline{r} = 0.4$, $\underline{p} = .003$), Apgar scores at birth ($\underline{r} = -0.38$, $\underline{p} < .02$), and hand function ($\underline{r} = 0.3$, $\underline{p} < .03$). Eighteen EEG reports were available for the RHP, 5 normal, 5 paroxysmal and 8 asymmetrical, and 8 LHP, 4 normal, 2 paroxysmal and 2 asymmetrical.

Thirty of the hemiplegic subjects had a CT brain scan available for analysis. Of these, 24 had evidence of a unilateral brain lesion, the rest were reported as normal. A further 5 had EEG results that were compatible with their diagnosis. Using the CT scan classification described by

Table 5

CT scan Grade Compared to EEG, Hand function and Schooling Classification

| | | Right hemiplegics | | | Left hemiplegics | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|
| EEG (seizures) | | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| CT scan | 1 | 2 | 2<br>(1) | -- | -- | -- | -- | 2 | 2 | -- |
| | 2 | 1 | -- | -- | 2 | 1 | -- | 3 | 1 | -- |
| | 3 | 1 | 1<br>(1) | 6<br>(2) | 2<br>(1) | 1 | -- | 3 | 2 | 6 |
| Hand function | | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| CT scan | 1 | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 1 | 3 |
| | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 3 | 2 |
| | 3 | 3 | 2 | 4 | 1 | 0 | 3 | 4 | 2 | 7 |
| Schooling* | | Reg | ResRm | Opp | Reg | ResRm | Opp | Reg | ResRm | Opp |
| CT scan | 1 | 5 | -- | -- | 2 | -- | -- | 7 | -- | -- |
| | 2 | 2 | 1 | 2 | 4 | 1 | -- | 6 | 2 | -- |
| | 3 | 6 | 2 | 2 | 2 | 1 | 1 | 8 | 3 | 3 |

EEG

0 = normal
1 = paroxysmal (ABN)
2 = asymmetrical (ABN)

CT SCAN

1 = normal
2 = ventricular enlargement
3 = white matter involvement

HAND FUNCTION (affected hand)

1 = able to grasp
2 = grasp between thumb and index finger
3 = unable to grasp

*Note: Reg = Regular, ResRm = Resource Room, Opp = Opportunity

Kotlarek et al. (1981) 6 scans were classified as normal Grade 1 (5 RHP, 1 LHP), 9 as being Grade 2 (4 RHP, 5 LHP) and 15 in Grade 3 (10 RHP, 5 LHP). The interaction of this classification of CT scan findings, EEG results, schooling and hand function are shown for RHP and LHP in Table 5. Generally, greater cerebral involvement, as seen on CT scan, was associated with more EEG abnormalities, poorer hand function and lower scholastic achievement, but these trends did not reach levels of statistical significance (possibly because of small numbers).

**Function of the dominant hand, as measured with the Trites Grooved Pegboard, was not significantly different between the three groups (RHP, LHP and Controls), nor did the hemiplegic groups differ on the rating scales of the severity of involvement of the affected hands. Half of the hemiplegic children had had a convulsive disorder at some time, 25% were still on anticonvulsive therapy. The seizure history of the Controls was negligible. The presence of seizures was significantly correlated with birth asphyxia, Apgar scores at birth and hand function of the affected hand in the hemiplegic groups. In 24 of 30 cases was the presence of a unilateral brain lesion confirmed with a brain scan (the other 6 appeared normal, but in 5 of the cases the EEG result was suggestive of a unilateral lesion).**

Table 6

Education and School Placement

| | Right hemiplegics (RHP) n=28 | Left hemiplegics (LHP) n=23 | Controls (C) n=30 | Statistics |
|---|---|---|---|---|
| School Placement | | | | ns |
| Regular classroom | 19** | 17 | 21 | |
| With resource room | 4 | 4 | 2 | |
| Opportunity class | 5 | 2 | 7 | |
| Remedial teaching | 9 | 5 | 3 | ns |
| Failed a grade | 11 | 6 | 6 | ns |
| Attention deficit (Parent rating) | 11 | 12 | 7 | ns |

**All values given are frequencies.

### (iii) Development and Education

An overview of development is given in Table 4. Because the presence of seizures had been shown to be an important factor in delayed walking and talking (Perlstein et al., 1957), the developmental milestones were subjected to a 3(diagnosis) by 2(absence or presence of seizures) two-way MANOVA. An overall effect of diagnosis on age at walking was found ($F(2,64) = 6.0$, $p < .005$), but not for talking (single words or sentences). Univariate analyses confirmed these findings. There was a significant effect for diagnosis on walking only ($F(2,64) = 10.13$, $p = .0002$). Post hoc analyses revealed that both hemiplegic groups walked later than the Controls, but there were no significant differences between the diagnostic groups. No effect for seizures could be demonstrated.

There were no significant differences between the groups as far as school placement, remedial teaching, school failure and attention deficits (as reported by the parents) were concerned (Table 6).

**There were no significant differences between the three groups for neurodevelopmental milestones or schooling, except that the hemiplegic groups started walking later than Controls. No association between the presence of seizures and delayed milestones could be demonstrated.**

## (B) The Cognitive Tests

The standardized subtest and total scores on the WISC-R are summarized in Table 7 and compared to those found by Nass et al. (1989) in a similar study in Table 8. All the subtests were administered to the subjects and Controls, except Digit Span which was administered to 20 subjects (13 RHP, 7 LHP) only. The standardized scores of the Verbal and Performance subtests of the WISC-R were subjected to a 3(RHP, LHP, C) by 2(sex) two-way MANOVA. No main effect for sex could be demonstrated nor was there any significant sex by diagnosis interaction. There was an overall effect for diagnosis alone ($F(2,22) = 2.0$, $p < .008$). A reanalysis of the same data using only the two hemiplegic groups did not demonstrate a main effect for diagnosis.

Generally, the LHP achieved the highest scores, compared to the RHP and Controls, on all the Verbal subtests as well as the VIQ, but this did not reach levels of statistical significance. Two subtests of the Performance Tests showed a significant effect of diagnosis with univariate analysis, Object Assembly ($F(2,78) = 3.75$, $p < .05$) and Coding ($F(2,78) = 3.54$, $p < .05$). A comparison of the three groups showed that in both cases the significant difference was between the RHP and the Controls, with the Controls achieving the higher scores. No significant differences could be demonstrated between the LHP and the Controls. Similarly, a diagnosis effect could be demonstrated for PIQ ($F(2,75) = 3.4$,

Table 7

Wechsler Cognitive Data

| | Rt hemiplegics (RHP) n=28 | Lt hemiplegics (LHP) n=23 | Controls (C) n=30 | Statistics |
|---|---|---|---|---|
| Information | 8.7** | 9.7 | 7.9 | ns |
| SD | 2.6 | 3.5 | 3.7 | |
| Similarities | 9.7 | 10.4 | 9.3 | ns |
| SD | 3.5 | 3.1 | 3.8 | |
| Arithmetic | 8.5 | 8.6 | 7.6 | ns |
| SD | 3.1 | 2.9 | 3.3 | |
| Vocabulary | 8.8 | 10.5 | 8.8 | ns |
| SD | 3.0 | 3.7 | 3.6 | |
| Comprehension | 9.2 | 10.3 | 8.9 | ns |
| SD | 2.8 | 2.7 | 2.6 | |
| Digit Span | 8.7 | 10.3 | 8.8 | ns |
| SD | 4.1 | 1.8 | 4.4 | |
| VIQ | 93.5 | 99.0 | 90.4 | ns |
| SD | 15.3 | 15.3 | 18.4 | |
| Picture Completion | 8.9 | 9.2 | 9.8 | ns |
| SD | 3.5 | 3.9 | 3.5 | |
| Picture Arrangement | 90.4 | 9.5 | 10.0 | ns |
| SD | 3.0 | 3.3 | 3.9 | |
| Block Design | 7.3 | 7.7 | 9.3 | ns |
| SD | 2.8 | 3.7 | 3.7 | |
| Object Assembly | 7.8* | 8.6 | 10.3* | *p<.03 |
| SD | 3.0 | 3.2 | 4.0 | |
| Coding | 7.2* | 7.1 | 9.4* | *p<.05 |
| SD | 4.1 | 3.6 | 3.8 | |
| Mazes | 8.0 | 7.9 | 9.1 | ns |
| SD | 2.8 | 3.6 | 3.7 | |
| PIQ | 86.0* | 88.4 | 97.9* | *p<.05 |
| SD | 15.0 | 17.0 | 20.6 | |
| FSIQ | 88.8 | 93.6 | 93.5 | ns |
| SD | 15.0 | 16.3 | 20.2 | |
| VIQ/PIQ difference | 7.5 | 10.5 | -7.5 | p<.001 |
| SD | 12.4 | 11.7 | 11.8 | |

**All values reported as means.

Table 8

A Comparison of Wechsler Data in Present Study with That Found by Nass et al. (1989)

| | Right Hemiplegia | | Left Hemiplegia | |
|---|---|---|---|---|
| | Present Study (n=28) | Nass et al. (n=15) | Present Study (n=23) | Nass et al. (n=13) |
| Verbal subtests | | | | |
| Information | 8.7** | 11.2 | 9.7 | 8.8 |
| SD | 2.6 | | 3.5 | |
| Similarities | 9.7 | 12.8 | 10.4 | 9.2 |
| SD | 3.5 | | 3.1 | |
| Arithmetic | 8.5 | 11.2 | 8.6 | 7.5 |
| SD | 3.1 | | 2.9 | |
| Vocabulary | 8.8 | 12.0 | 10.5 | 8.9 |
| SD | 3.0 | | 3.7 | |
| Comprehension | 9.2 | 10.7 | 10.3 | 8.0 |
| SD | 2.8 | | 2.7 | |
| VIQ | 93.5 | 107 | 99.0 | 92.5 |
| SD | 15.3 | | 15.3 | |
| Performance Subtests | | | | |
| Picture completion | 8.9 | 10.5 | 9.2 | 10.0 |
| SD | 3.5 | | 3.9 | |
| Block design | 7.3 | 9.8 | 7.7 | 8.2 |
| SD | 2.8 | | 3.7 | |
| Mazes | 8.0 | 10.2 | 7.9 | 8.0 |
| SD | 10.2 | | 3.6 | |
| PIQ | 86.0 | 96 | 88.4 | 90 |
| SD | 15.0 | | 17.0 | |
| FSIQ | 88.8 | 102.5 | 93.6 | 90 |
| SD | 15.0 | | 16.3 | |

**All values reported as means.

$p < .05$) and the VIQ/PIQ difference ($F(2,75) = 16.6$, $p < .05$). The RHP's scores were lower than the Controls on the PIQ, resulting in higher VIQ/PIQ differences. The VIQ/PIQ difference was also significantly higher for the LHP compared to the Controls. There were no significant differences on full scale IQ between the groups, but this is not surprising as IQ was one of the criteria for matching the Controls.

According to Vega et al. (1969), the Vocabulary and Block Design subtests are the clearest measures of Verbal and Performance abilities respectively. On Vocabulary, the LHP did obtain the highest scores but this was not significant. On Block Design the RHP and LHP scored lower than the Controls, and this difference approached significance ($F(2,78) = 2.6$, $p = .08$). A division of the study groups above and below the mean on all the Wechsler data, and carrying out a Chi square analysis confirmed all the above findings.

Regrouping of the subtests into a Verbal Comprehension Factor, a Perception-Organization Factor and a Distractibility Factor (Asarnow et al., 1987) did not help differentiate between groups based on either diagnosis or sex, or their interaction. These groupings will not be considered in further discussions.

As shown in Table 8, the results of the present study differs from that found by Nass et al. (1989), in that the LHP in this study did not achieve such low scores overall. The RHP group in the Nass study scored higher than the RHP children in the present study, but demonstrated a similar trend of poorer Performance than Verbal scores and IQ. The significance of these findings will be discussed in the next chapter.

**The RHP did not differ significantly from the Controls on Verbal subtests, but did so on PIQ, Object Assembly, Coding and VIQ/PIQ differences. The LHP, although never reaching a level of significance as compared to the Controls, demonstrated a consistent superiority across Verbal tests and some generalized low scores on Performance tests. The VIQ/PIQ difference was significantly higher for the LHP than the Controls.**

### (C) Tests of Language Ability

The results of three language tests were examined, namely, the Peabody Picture Vocabulary Test - Revised (PPVT - standard scores), the total standardized language score on the Clinical Evaluation of Language Fundamentals - Revised (CELF-R), and two scores on the Active - Passive (A-P) Test, the total correct responses and latencies of response both expressed as a z-score (see Table 9). These variables were highly correlated, PPVT with CELF-R ($r = .7$, $p < .0001$), PPVT with the A-P Test correct responses and latencies scores ($r = .5$, $p = .0001$, and $r = .42$, $p = .0001$), and the total language score on the CELF-R and A-P Test correct responses

Table 9

Tests of Language Ability

| | Right hemiplegics (RHP) n=28 | Left hemiplegics (LHP) n=23 | Controls (C) n=30 | Statistics |
|---|---|---|---|---|
| PPVT standard scores | 91.3** | 95.3 | 91.0 | ns |
| SD | 18.7 | 18.7 | 18.5 | |
| CELF-R total language score | 84.5 | 88.7 | 87.0 | ns |
| SD | 16.8 | 18.0 | 20.3 | |
| Active-Passive Test | | | | |
| Correct responses z-score | -1.89 | -1.14 | -0.93 | ns |
| SD | 2.2 | 2.3 | 2.2 | |
| Latencies z-score | -2.1* | -0.81 | -0.8* | *p<.05 |
| SD | 2.0 | 1.8 | 1.9 | |

**All values reported as means.

and latencies ($r = .47$, $p = .0001$, and $r = .34$, $p = 0.002$). The PPVT, CELF-R and A-P Test (both measurements) were also highly correlated with the VIQ on the WISC-R ($r = .74$, $p = .0001$; $r = .77$, $p = .0001$; $r = .43$, $p = .0001$ and $r = .24$, $p < .03$).

The data were subjected to a 3(diagnosis) by 2(sex) two-way MANOVA. There was an overall main effect for diagnosis ($F(2,42) = 1.69$, $p < .02$), but not for sex or the interaction. In particular, there was a significant effect for diagnosis on univariate analysis for the A-P Test latencies ($F(2,75) = 3.11$, $p = .05$). Post hoc analysis revealed that this significant difference was limited to the RHP and Controls ($p < 0.05$), the RHP having longer latencies ($m = -2.1$, $SD = 2.0$) than the Controls ($m = -0.8$, $SD = 1.9$).

**The only variable that significantly differentiated the three groups was the latencies on the A-P Test, which showed that the RHP scored significantly longer latencies than the Controls.**

### (D) Tests for Visual-Perceptual Skills

The tests that were examined for visual-perceptual skills were the Mazes subtest on the WISC-R, The Raven's Progressive Matrices, the Developmental Test of Visual Motor Integration (VMI), the Motor-free Visual-Perceptual Test (MVPT) (all standard scores), The Money Road Map (percentile

Table 10

Tests for Visual-Spatial Skills

| | Rt hemiplegics (RHP) n=28 | Lt hemiplegics (LHP) n=23 | Controls (C) n=30 | Statistics |
|---|---|---|---|---|
| Wechsler Mazes | 8.0** | 7.9 | 9.1 | ns |
| SD | 2.8 | 3.6 | 3.7 | |
| Ravens IQ | 85.3* | 90.7 | 97.1* | *p<.05 |
| SD | 16.2 | 14.4 | 16.1 | |
| VMI standard score | 87.2* | 88.7 | 98.1* | *p<.05 |
| SD | | | | |
| Motorfree visual-perceptual quotient | 87.3 | 89.4 | 93.9 | ns |
| SD | 17.0 | 25.7 | 20.1 | |
| Facial recognition raw score | 38.3 | 38.8 | 38.5 | ns |
| SD | 5.4 | 5.8 | 5.7 | |
| Judgment of line-orientation raw score | 11.6 | 11.9 | 14.3 | ns |
| SD | 7.9 | 9.5 | 8.5 | |
| Money road map percentiles | 42.7 | 31.5 | 35.6 | ns |
| SD | 28.1 | 31.5 | 32.3 | |

**All values reported as means.

scores) and the Tests of Facial Recognition and Line Orientation (raw scores) (Table 10). A main effect for diagnosis could be demonstrated ($F(2,36) = 2.09$, $p < .002$), but not for sex or the interaction. A diagnosis effect was found on univariate analysis for The Raven's Matrices ($F(2,75) = 4.0$, $p < .03$) and the VMI ($F(2,75) = 4.11$, $p < .03$). Post hoc tests revealed that in both cases it was the RHP ($m = 85.3$, $SD = 16.2$ and $m = 87.2$ $SD = 14.5$) that scored significantly less than the Controls ($m = 97.1$, $SD = 16.1$ and $m$ 98.1, $SD = 16.0$) with the LHP in between ($m = 90.7$, $SD = 14.4$ and $m = 88.7$, $SD = 16.2$). Differences on all the other tests were not significant.

As adequate norms are not available for the Facial Recognition Test or the Line Orientation Test, raw scores of the three groups, who had similar age distributions, were compared. Marked impairment on both tests for all three groups was indicated, based on guidelines set by Benton et al. (1983). This occurred especially on the Line Orientation task, where many of the subjects in all three groups obtained scores equal to those reported for 7 year olds (grand mean = 7.5 years, $SD = 2.6$), even when their mean chronological age was 10.1 years ($SD = 2.4$). It would seem that these tests are sensitive not only to right hemispheric lesions, but also to general intellectual impairment in this population group.

On univariate analysis, a significant main effect for sex could be demonstrated for the MVPT perceptual quotient

($F(1,76) = 4.55$, $p < .05$). Although the females were generally older than the males, post hoc analyses revealed that it was the males who did significantly better at this task ($p < 0.05$). There was no effect for diagnosis or for a sex/diagnosis interaction.

**The results of the visual-spatial tests can be summarized as follows: One cluster of tests showed no marked deficits over all three groups (WISC-R Mazes, Motor-free Visual Perceptual Test), one cluster showed a marked deficit in all three groups (Facial Recognition, Line Orientation, Money Road Map) and two tests differentiated between RHP and Controls (Raven's Matrices and VMI) with the LHP scoring in between. No sex differences could be demonstrated across the diagnostic groups.**

### (E) The Wide Range Achievement Test

The standardized scores of the three subdivisions of the WRAT-R (Reading, Spelling and Arithmetic) are shown in Table 11. There was no significant diagnosis effect for Reading, Spelling and Arithmetic, nor a sex effect or sex/diagnosis interaction.

Multiple regressions were carried out to determine which variables would predict academic achievement as measured by the three subscores of the WRAT. The variables that were included were all the cognitive and perceptual data, as well as diagnosis, age at testing, sex, familial sinistrality score, function score of the affected hand, the severity of brain damage as assessed by the CT scan classification, birth weight, gestational age, the presence of problems during pregnancy, the presence of birth asphyxia, developmental delay, the presence of seizures and the family's socioeconomic score. Only the two hemiplegic groups were considered in these regressions. A $p$ value $< .01$ was considered significant. The only significant predictor for both Reading and Mathematics was the presence of developmental delay. No predictors for Spelling could be determined.

**There were no significant differences between the groups for the three subdivisions of the WRAT-R. Developmental delay emerged as the only significant predictor of Reading and Mathematics.**

## (E) Factors that could Modify the Outcome of Cognitive and Perceptual Measures.

### (i) Familial Sinistrality

Parental handedness was established using a modified version of The Edinburgh Inventory (Oldfield, 1971). A familial sinistrality (FS) score was computed using this procedure and the information from the questionnaire on handedness of the extended family (detailed description in

Table II

Other Variables

| | Right hemiplegics (RHP) n = 28 | Left hemiplegics (LHP) n = 23 | Controls (C) n = 30 | Stats |
|---|---|---|---|---|
| Familial Sinistrality | 2.2** | 2.6 | 1.8 | ns |
| SD | 1.9 | 1.8 | 1.7 | |
| Treatment | 3.8* | 4.1* | 0.2 | p < 0.5 |
| SD | 2.9 | 3.0 | 0.5 | *ns |
| WRAT-R standard scores | | | | |
| Reading | 86.8 | 93.1 | 82.8 | ns |
| SD | 16.0 | 24.4 | 21.2 | |
| Spelling | 81.5 | 84.4 | 80.5 | ns |
| SD | 16.4 | 21.0 | 15.7 | |
| Arithmetic | 82.0 | 82.0 | 87.4 | ns |
| SD | 15.6 | 10.9 | 21.2 | |

**All values reported as means.

previous chapter). The mean FS scores are shown in Table 11. Differences between groups did not reach significance. Twenty-one (of 63) subjects had a FS score of 3 or more (33.3%). When the hemiplegic groups were considered separately, without the Controls, the incidence of familial sinistrality increased to 42.5% (17 of 40).

For computational purposes, the subjects were divided into two groups. Those with FS scores of three or more were considered to have a positive family history and subjects whose scores were less than three, negative. No overall effect for FS could be demonstrated for any of the variables already discussed, nor an interaction effect with diagnosis or sex.

**In summary, no effect for familial sinistrality could be demonstrated.**

### (ii) Seizures and Intracranial Pathology

The cognitive data and descriptive statistics were subjected to a 2(diagnosis) by 2(sex) by 2(presence or absence of seizures) three-way MANOVA. There was no main effect for seizures or for any interactions with diagnosis or sex. Univariate analyses demonstrated a seizure effect for PIQ ($F(1,32) = 8.46$, $p < .008$), the VIQ/PIQ difference ($F(1,32) = 5.1$, $p < .05$) and birth asphyxia ($F(1,32) = 7.01$, $p < .02$). Post hoc tests showed a significant increase in seizures with an history of birth asphyxia (p < .05). The presence of seizures significantly depressed the PIQ (p < .05).

A three-way MANOVA was performed using sex, diagnosis (excluding Controls) and CT-scan results (both classifications alternatively). There was no overall main effect for the type of CT-scan abnormalities only, nor for its interaction with sex and diagnosis. An attempt to analyze the EEG data in a similar fashion failed because of small numbers, even when the results were collapsed into two groups, normal and abnormal.

**An overall main effect of seizures was demonstrated for Performance IQ and birth asphyxia. No main effects for CT scan results could be demonstrated.**

### (iii) Treatment

The compilation of the 'treatment score' based on the duration of therapy was described in the previous chapter. The mean (SD) score for each group is given in Table 11. Univariate analyses using 'treatment' as a dependent variable demonstrated a significant effect of diagnosis ($F(2,54) = 15.6$, $p = .0001$). Post hoc tests revealed that the two hemiplegic groups received significantly more treatment than the Controls.

A 3(diagnosis) by 2(sex) by 10(treatment) three-way MANOVA was carried out on all cognitive outcome variables, which showed a significant main effect for 'treatment' on the Pillai's Trace Statistic only ($F(2,117) = 1.3$, $p = .044$). Univariate analysis showed an effect of treatment on the VIQ/PIQ difference ($F(9,53) = 2.4$, $p < .05$). *Post hoc* analyses identified that generally significant differences were reached between those subjects who had received no treatment and those who had received a score of more than seven, the latter group having higher VIQ/PIQ differences. Because the Controls' 'treatment' was negligible, it was decided to repeat the three-way MANOVA using the two hemiplegic groups only. No significant overall effect for treatment could be shown. The effect of 'treatment' on the VIQ/PIQ difference on univariate analysis, remained significant ($F(9,25) = 2.7$, $p < .05$)

**Both the RHP and the LHP received significantly more 'treatment' than the Controls. A main effect of treatment could not be shown for the cognitive outcome measures of the hemiplegic groups. Univariate analyses demonstrated an effect of treatment for the VIQ/PIQ difference only. Treatment scores over seven were associated with a bigger VIQ/PIQ difference, than when no treatment was received at all.**

### (iv) Other variables

Two separate MANOVAS were carried out with diagnosis, sex and alternatively birth asphyxia and problems during pregnancy as the class variables and the cognitive outcome measures as dependant variables. No main effect for problems during pregnancy could be demonstrated, nor for its interactions with diagnosis or sex. A reanalysis of the data for the two hemiplegic groups only, gave the same results. Similarly a significant main effect for birth asphyxia could not be demonstrated. Univariate analyses did demonstrate a significant effect for asphyxia on Performance IQ ($F(1,51) = 6.9$, $p < .02$), VIQ/PIQ differences ($F(1,51) = 4.1$, $p = .05$), VMI ($F(1,51) = 4.2$, $p < .05$), and MVPT ($F(1,51) = 10.6$, $p < .003$), all tests considered to have a significant visual-spatial content. In all cases *post hoc* analyses showed that subjects who had an history of birth asphyxia achieved the lowest scores. The data were reanalyzed for the two diagnostic groups only. Once again, there was no main effect shown for birth asphyxia. With the exception of the VIQ/PIQ differences, no significant effects for asphyxia were found with univariate analyses.

A stepwise regression analysis procedure was used to examine the multivariate associations of the significant independent variables, already described in the previous chapter (and summarized in Table 12), using the various cognitive tests as outcome measures. A value of $p < .01$ was considered significant. The significant results are given in Table 12. There were no significant predictors found for the latencies on the Active-Passive Test, WISC-R Mazes, Facial Recognition Test, Judgement of Line Orientation or the VMI. Two significant predictors were identified, problems during pregnancy (generally for standard IQ and language measures), and developmental delay, a significant predictor for the rest of the outcome measures. Inclusion of 'treatment' as an independent variable did not lead to a different outcome.

Interactions of birth asphyxia, seizures, and the PIQ had been demonstrated in several statistical analyses. It was therefore somewhat surprising that 'problems during pregnancy' emerged as the most significant predictor of cognitive outcome measures, although it was more predictive for verbal than non-verbal tests. The possibility was entertained that the two variables, asphyxia and problems during pregnancy, were in fact two end points in the spectrum of a single variable, and that the statistical presence of one might mask the effects of the other. A single variable with four levels was generated. Level one was no history of birth asphyxia or problems during birth; level two; problems during pregnancy only. Level three signified birth asphyxia only, and level four included both. The cognitive outcome measures were subjected to a 3(diagnosis) by 4(birth factor) two-way MANOVA, and a stepwise regression, using the birth factor as an independent variable, with all the other independent

Table 17

Significant Predictors of Outcome of Cognitive Measures as Determined with Multiple Regressional Analyses

| Predictors* | Diag | Age | Sex | FS | HF | CT Scan | Gest | BWT | PrPr | Asphyxia | Seiz | DevDel | SES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outcome variables | | | | | | | | | | | | | |
| FSIQ | X | | | | | | | | X | | | | |
| PIQ | | | | | | | | | X | | | X | |
| VIQ | | | | | | X | | | X | | | X | |
| CELF-R Total Language Score | | | | | | | | | | | | X | |
| PPVT standard score | X | | | | | | | | | | | X | |
| Active-Passive Test correct responses | | | X | | | | X | | X | | | X | |
| MVPT | X | | | | | | | | | | | X | |
| Raven's IQ | | | | | | | | | | | | X | |
| Money road map | | | | | | | | | | | | X | |

*Note: Diag = Diagnosis
FS = Familial sinistrality
HF = Hand function
Gest = Gestational age
BWT = Birth weight
PrPr = Problems during pregnancy
Seiz = Seizures
DevDel = Development delay
SES = Socioeconomic status

variables already mentioned (except birth asphyxia and problems during pregnancy). No overall effect of this birth factor for the cognitive measures was found, nor for the interaction with diagnosis. Univariate analyses showed an effect of this birth factor on the Money Road Map percentiles ($F(3,50) = 3.22$, $p < .05$), developmental delay ($F(3,50) = 7.18$, $p = .0005$) and seizures ($F(3,50) = 3.57$, $p < .03$). Post hoc analysis showed significantly more seizures with asphyxia, and problems during pregnancy was associated with late walking. A repeat analysis using only the diagnostic groups produced similar results. Multiple regression did not identify the birth factor as a significant predictor of cognitive outcome measures.

**It would appear that in this study, problems during pregnancy and birth asphyxia are two discrete and independent variables each with its own influence on outcome measures, and that it is not useful to consider them as two points in the same spectrum. Birth asphyxia was associated with seizures and lower scores on Performance tasks, while problems during pregnancy emerged as a significant predictor of general intelligence and measures of language abilities (together with developmental delay).**

# CHAPTER V: DISCUSSION

## (A) Description of Subjects

During recruitment, and after eventual selection, there was an unbalanced distribution of subjects. There were more right hemiplegic subjects than left hemiplegics, and fewer females than males. Similar unbalanced distributions have been reported before (Annett, 1973; Levine et al., 1987; Nottidge et al., 1991; Perlstein et al., 1957). Possible explanations for the relative paucity of right-lesioned females, such as differences of maturation rates of the male and female brain and the orientation of the head during delivery, have been referred to before.

### (i) Pregnancy and Birth History

In this study, hemiplegic subjects tended to be more premature and of lower birth weight, similar to populations described by Hagberg et al., 1984 and Powell et al., 1988, although the differences were significant only when the LHP and Controls were compared. An association between small-for-gestational-age and hemiplegia could not be demonstrated.

In the present study 39% of the hemiplegic subjects had no history of birth asphyxia, and in nearly half of them no problems during pregnancy had been suspected either. A similar prevalence of negative intrapartum findings have been reported before (45%, Hagberg et al., 1984; 55%, O'Reilly et al., 1981; and as high as 62%, Cohen et al., 1981). This finding lends some credence to intra-uterine causes for spastic congenital hemiplegia. Furthermore, as Michaelis et al. (1980) pointed out, a history of birth asphyxia does not rule out a prenatal cerebral insult, possibly because of early damage to the respiratory center (Wigglesworth, 1984). Even in this highly selected population of subjects with congenital cerebral palsy, some variability exists. The cerebral insult could have occurred any time from conception to birth, though the majority were probably affected in the last trimester, the most common period for "silent" perfusion insufficiency (see Hagberg et al., 1984).

### (ii) Development

Perlstein et al. (1957) found that left (as opposed to right) hemiplegics walked and talked earlier even when differences in intelligence were negligible, though the differences in milestones did not reach significance. The present study does not confirm these findings. Perlstein's findings of a significant association between the presence of seizures and developmental delay, could not be demonstrated in this study.

### (iii) Severity of Brain Injury

In the present study, not all hemiplegics had the locus of their cerebral lesion confirmed with CT scan. As far as possible bilateral lesions were excluded on neurological examination. Supportive evidence for the unilaterality of cerebral involvement comes from the results obtained on the Trites Grooved Pegboard. Brown, Schumacher, Rohlman, Etlinger, Schmidt and Skreczek (1989) found the "good" hand function of children with hemiplegia to be compromised on a pointing task, compared to normal children of similar age. In the present study, the hemiplegic children's 'good' hand scores were lower than the Controls, but the difference was not significant. The hemiplegic groups' means were all between the normative mean and one standard deviation above for the functional hand. In two previous studies, results on a similar test (the Annett Pegboard) were as low as -6.66 SD (Annett, 1973; Kiessling et al., 1983). When subjects with such poor manual performance are included in a study, the possibility of bilateral cerebral involvement cannot be excluded. It would be naive to expect that a cerebral insult that involves one hemisphere would not also have implications for the other (possibly with the exclusion of anatomically localized abnormalities), but none of the present subjects had significant contralateral involvement, based on clinical grounds, and on the results of the special investigations that were available.

The prevalence of seizure disorders (49%) is similar to that found in other studies (58%, Cohen et al., 1981; 51%, Levine et al., 1987; 43%, Perlstein et al., 1957). The recurrent seizure rate later in life was only 25%, not as high as the 52% reported by Cohen et al. As subjects with uncontrolled epilepsy and severe mental retardation were excluded from the present study, the seizure rate is probably not representative of the total population. The presence of seizures was significantly correlated with birth asphyxia, Apgar scores at birth and the severity of the hemiplegia as measured by the affected hand function, but not with intrauterine complications. These findings may imply that the etiological factors associated with hemiplegia in utero and perinatally may be different, or be an indication that the cerebral injury at different stages of development lead to different neurological sequelae (see later).

Several studies have demonstrated that the size of the lesion on CT scan predicts the severity of aphasia (Kertesz et al., 1979), seizures and mental retardation (Cohen et al., 1981; Levine et al., 1987). A significant association between cortical and subcortical cavity, epilepsy, mental retardation, severity of hemiparesis and attendance of special schools was found by Kotlarek, et al. (1981) and Levine et al. (1987). In the present study these trends were not statistically significant.

## (B) Cognitive Tests

The results of the cognitive tests in this study do not follow the expected association of verbal deficits with left lateral lesions and performance deficits with right sided lesions. The LHP do show a general, but nonsignificant superiority in verbal skills. A similar nonsignificant LHP advantage for Verbal subtests was also demonstrated in other studies (Annett, 1973; Gersten, et al., 1972; Perlstein et al., 1957; Reed et al., 1963; Riva et al., 1986; Simpson et al., 1971), although not all these studies involved children only. An expected significant deficit of visual-spatial skills in LHP, as had been demonstrated in a previous study (Riva et al., 1986), was not found either. Specific subtests have been implicated for the lower PIQ in LHP, Object Assembly and Mazes (Kershner et al., 1974), Mazes and Block Design (Nass et al., 1990) and especially Block Design, but also Object Assembly, Picture Completion and Picture Arrangement (Gersten et al., 1972). In the present study, LHP performed nearly as poorly on Block Assembly and Coding as RHP, but none of these results was significant when compared to the Controls, possibly because of the small numbers involved or matching on IQ.

Studies that did find specific subtests on the Verbal subtests to be depressed found lower scores for RHP than LHP on Similarities (Kershner et al., 1974) and Arithmetic, Similarities and Vocabulary (Gersten et al., 1972). Although the RHP group generally did worse than the LHP on the Verbal subtests, none of the differences was statistically significant. The rather surprising finding in the present study of a significantly poorer performance on Coding and Object Assembly in RHP as compared to Controls has not been reported before.

The findings of Nass et al. (1989), who tested subjects with congenital hemiplegia on Wechsler Intelligence Tests deserve a closer look at this point (see Table 8). In their study, they were not able to demonstrate a significant difference between right and left-lesioned subjects on Performance subtests, but did demonstrate that the left-lesioned (RHP) subjects' scores on the Verbal subtests were significantly higher than the right-lesioned (LHP) subjects. The results of the present study did not replicate these findings. One reason could be that the full scale IQs (FSIQs) of the two groups were similar in the present study, and the FSIQs in the Nass et al. study were 102 and 89 for the RHP and LHP respectively, a difference that was significant. It is possible that the LHP and RHP groups in the Nass study are not directly comparable because of the initial discrepancies in IQ. Even so, although Nass et al. did not comment on it, the RHP had scores on Performance subtests that were markedly depressed in comparison with their Verbal subtests. A similar trend was found in the present study. Nass et al. are the first to suggest that the left-right maturational gradient could explain some of the findings of the organization of lateralized skills in congenital hemiplegia, based on the generally poor performance of the LHP. The evidence they offer could not be considered to support this hypothesis. Injury to the less mature right hemisphere, would lead to impairment of visual-spatial functions, but should not interfere with development of language in the left hemisphere. The left-right maturational difference implies that the left hemisphere is more mature at birth, and therefore less plastic and less likely to be involved in an interhemispheric transfer of visual-spatial skills. These subjects should demonstrate near normal language development and some deficiencies of visual-spatial skills (as was the case in the present study). The less mature (and more plastic) right hemisphere would facilitate interhemispheric transfer of language abilities, which may compromise both verbal and visual-spatial development. It is the results of the RHP group in the Nass study, which they do not emphasize, that suggests that the maturation gradient is an important factor in post injury reorganization, and not the general poor performance of their left hemiplegic group.

The unexpected deficits in the Performance subtests in RHP found in the present study, may reflect a interhemispheric transfer of verbal functions after left hemisphere damage, from the more mature left hemisphere to a less mature right hemisphere. The right side has to reorganize intrahemispherically at the expense of the visual-spatial skills, possibly due to an 'overcrouding' effect. Yet, when the less mature right hemisphere is damaged, visual-spatial skills cannot be accommodated by the more mature (and less plastic) left hemisphere and so no deficits of verbal functions are found in LHP. This implies that some measure of innate dichotomy must exist, and that cerebral plasticity does compensate for early brain damage. However, the compensation is incomplete and varies with the side of lesion and the maturational status of the hemisphere involved.

### (C) Tests of Language Ability.

The tests for language ability and VIQ were highly correlated in this sample. Means for the respective groups were similar for the PPVT and the CELF-R. It was the Active-Passive Test that differentiated between the groups. The latencies for the LHP and Controls were the same, but they were markedly longer for the RHP groups. This tendency towards longer latencies in left-lesioned subjects was also demonstrated by Aram et al. (1987) on tests of lexical retrieval, and Dennis et al. (1975) using the same A-P Test on posthemispherectomy subjects and Kohn (1980) in patients with left focal epilepsy. Although these results did not reach significance, inspection of the number of correct responses on the A-P Test also revealed a tendency for the RHP to have made the most mistakes, compared to the Controls, with the LHP scoring in between. In their studies of congenital hemiplegics, Kiessling et al. (1983) and Rankin et al. (1981) found that RHP performed less well than LHP and controls on measures of syntactic awareness (neither of these studies examined deficits in visual-spatial skills). The poor performance of the RHP cannot be attributed to a general lower intelligence as the control group was matched on IQ. At this point it must be assumed that the A-P Test identified a 'true' verbal deficit.

Whatever mechanisms of plasticity and recovery of language functions take place after perinatal left hemisphere lesions, they are adequate for early acquired verbal abilities. This would explain the near identical achievement on measures such as the WISC-R Verbal subtests, PPVT and CELF-R, and might also explain some of the contradictory findings in previous research on hemiplegic children. Syntactic understanding of 'passive' sentence structure is a late acquired skill (probably only achieved at school-going age - Dennis et al., 1985), and might have to compete with a limited number of the remaining synaptic sites (possibly in the right hemisphere) for its development after an insult to the left hemisphere (Bishop, 1981). Although an adequate level of competence in the understanding of syntax develops, it is compromised, as demonstrated by the longer latencies.

These findings do not contradict the hypothesis of the effect of a right-left maturational gradient on cerebral plasticity. After early left-sided lesions, the right hemisphere may take over verbal functions, and early acquired linguistic skills do not suffer. It is the later acquired verbal skills that may not develop adequately because of an already 'overcrowded' right hemisphere.

### (D) Tests for Visual-Spatial Skills

As in the case of the Performance Tests of the WISC-R, the RHP again show an unexpected, but significant deficit on some of the tasks; the VMI and the Raven's Progressive Matrices, relative to Controls.

The poor performance on the VMI may be due to a true visuo-motor deficit, or be secondary to compulsory use of the less competent left hand of the RHP. Closer inspection of the data reveals that both hemiplegic groups' performance was less efficient on this task than the Controls. A failure of the LHP/Control difference to reach significance might be due to small numbers available for analysis. The VMI scores were significantly, but negatively correlated with treatment ($r$ = -.4, $p$ < .001). The negative correlation implies that, the more treatment a subject received (a possible reflection of the severity of the handicap), the worse their performance on the VMI. The VMI was also significantly correlated with performance on the pegboard ($r$ = .33, $p$ < .003). The lower scores on the VMI are probably a reflection of the pathological motor involvement of cerebral palsy, rather than an isolated perceptual deficit. Two recent studies have found that drawing was impaired in right and left lesioned subjects, whether it is children (Stiles-Davis, Janowsky, Engel, & Nass,

1988) or adults (Kirk et al., 1989).

The Raven's Matrices is a test that combines general intellectual abilities with visual-perceptive capabilities (De Renzi et al., 1966). In the present study, general intelligence was controlled across the groups. The Raven's Matrices was not found to be sensitive to differences between left and right lesions in studies of De Renzi et al. (1966) and Gersten et al. (1972), yet the Raven's Intelligence Coefficient (RIQ) was significantly depressed in the RHP subjects in this study. The RIQ showed a higher correlation with PIQ ($\underline{r}$ = .79, $\underline{n}$ = 81, $\underline{p}$ =.0001) than VIQ ($\underline{r}$ = .66, $\underline{n}$ = 81, $\underline{p}$ = .0001), and the difference was significant ($\underline{t}$ = 2.45, $\underline{p}$ <.01). The poor performance of the RHP on the Raven's could be interpreted as representing some measure of visual-spatial deficit, especially in light of the specific deficits found on the Performance subtests of the WISC-R.

The inability of the WISC-R Mazes and Motor-free Visual Perceptual Test to demonstrate any deficits might be due to the relative simplicity of the tasks. Kohn et al. (1974) had demonstrated in post-hemispherectomy patients that only visual-spatial tests that require more complicated skills ('later acquired') were sensitive enough to highlight specific perceptual deficits in subjects with early unilateral brain damage. It was, therefore, somewhat surprising that the Money Road Map Test did not discriminate the hemiplegic subjects from the Controls, as the complicated skills necessary to complete this task are considered to be 'later acquired' (Kohn et al., 1974). 'Mental manipulation in space' has been shown to be the one visual spatial skill that placed the most "asymmetrical demand on cerebral resources" (right hemisphere) with regional blood flow studies (Deutsch et al., 1988, p 445). In fact, all the groups achieved scores under the 50th percentile on the Money Road Map (Table 10). The generally depressed performance over all the groups may have been merely a developmental phenomenon; retesting the subjects at an older age might reveal more specific deficits. 'Position in space' development is complete at 7 to 9 years, and 'spatial relationships' improve through approximately 10 years of age (Williams, 1983). The mean age of all three groups is about 10 years, so that the skills needed to complete the MRM might still be evolving for hemiplegics and Controls alike. A similar explanation might also apply to the generalized poor performance of all three groups on the Facial Recognition and Judgement of Line Orientation Tests.

### (E) The Wide Range Achievement Test

Rourke et al. (1978) were able to demonstrate a particular relation between WISC VIQ/PIQ discrepancies and differential patterns of deficit on the WRAT-R. The present study did not replicate these findings. The three groups did not achieve scores on the subtests that were significantly different. Kershner et al., 1974, also found no differences in their study of congenital hemiplegics. The association of poor arithmetic skills and visual-spatial deficits, described by Rourke et al. was also not found. The mean scores in the present study, in the low average range, probably reflect the general low average intelligence of the three groups. The WRAT-R was not a useful indicator of specific perceptual deficits in this population.

## (F) Factors that could Modify the Outcome of Cognitive and Perceptual Measures.

### (i) Sex Differences

No sex effects could be demonstrated in this study. There are several explanations for this, the most parsimonious being that indeed no such differences exist. However, faced with some methodological constraints in the present study, it would be difficult to defend this point of view without reservation. There is some evidence that sex differences in higher mental functions are typically in the order of one-quarter of a standard deviation (Springer et al., 1981). This implies that there is great overlap in the distribution of abilities across the sexes. The small numbers investigated, or the tests used in the present study, may not have been adequate to demonstrate any differences between the sexes. On the other hand, the question should be asked whether, if these differences are so difficult to demonstrate, they are of any clinical importance.

Finally, subjects with congenital hemiplegia might not be the ideal population for demonstrating sex effects of recovery from unilateral brain damage. Even though differences in brain maturation have been demonstrated between males and females (see Andrews, 1977), the insult might have occurred when the brain still had the capacity for extensive cerebral reorganization (neuroplasticity) irrespective of sex. A study of later acquired brain lesions might better highlight sex-specific differences in mechanisms of recovery.

The singular finding of the better performance of males than females on the MPVT is somewhat surprising. Males are generally considered to be superior on tasks of a visual-spatial nature (Benton et al., 1983; Maccoby & Jacklin, 1974), although several exceptions have been documented (see Marshall, 1973). Buffery and Gray (1972) argue that male superiority on visual-spatial tasks only appears when manipulation of spatial relationships are involved. Marshall points out that Buffery et al.'s notion of 'manipulation' was poorly defined and therefore in need of validation. In the present study, it was on the one visual-spatial test that required no manipulation, that the males excelled. When compiling the normative data for the Motor-free Visual Perceptual Test, sex differences were tested for by an analysis of variance, and these were not significant at the .05 level (Colarusso et al., 1972). No other explanation for the sex differences in the present study is obvious. Either this is a true sex effect, one random effect out of many, or it reflects a cultural phenomenon, such as the advent of computer games, that may make this test easier for children (mainly boys?) who play them.

It must be emphasized that the above discussion should not detract from the fact that the present study could not demonstrate any sex differences in the organization of lateralized cerebral functions after unilateral brain lesions.

### (ii) Familial Sinistrality

The prevalence of familial sinistrality of 33.3% for all three groups (or 42.5% for the hemiplegics) is similar to that found by Annett (1973, 45%). It is not known if this prevalence of familial sinistrality also represents the normal population, but, Pipe (1987) has found familial sinistrality to be significantly higher in children with developmental delay, than normal children. As with the effect of sex differences, no influence of familial sinistrality on the recovery of lateralized brain functions could be demonstrated. Again, the differences may be too subtle to detect with a limited number of subjects, or the effects might be more impressive in subjects with later acquired lesions. The greater potential for neuroplasticity and the resultant reorganization of lateralized hemispheric skills in the fetus or newborn, as opposed to later acquired lesions, may mask the effects of cerebral organization due to the presence of familial sinistrality.

### (iii) Seizures and Intracranial Pathology

The probability that seizure activity, and not a different cerebral reorganization, may be responsible for the patterns of deficits that have been found, has to be considered. Perlstein et al. (1957) found that seizures were associated with lower intelligence, although no specific cognitive deficits were discussed. Neither the presence of seizures nor brain damage as measured on the CT scan emerged as significant predictors of the cognitive and perceptual outcome measures on analyses with multiple regressions. Furthermore, the difference in the prevalence of seizures in the two diagnostic groups was not significant at any time (early versus current).

An association between the presence of seizures and lowering of PIQ was demonstrated. It is possible that the presence of a convulsive disorder may have modified the acquisition of visual-spatial abilities. It was the RHP that had significantly lower PIQ scores than Controls. Yet, it would be expected that in this group, the seizure activity would have its origin in the left (speech) hemisphere. The presence of seizures may merely be a marker of perinatal brain damage, which would explain the high correlations of seizures with birth asphyxia, Apgar scores and 'affected' hand function.

Vargha-Khadem, Isaacs, Papaleloudi, Polkey and Wilson (in press) have recently demonstrated in children with brain damage, that the hemispheric side of lesion was not a significant predictor of performance measures of memory, but that the presence or absence of seizures were highly significant. Hebb (see discussion in Taylor, 1984) suggested two types of intelligence. Intelligence A is the ability to to engage in new mental constructions, such as abstract reasoning and visual-spatial skills. It is this type of intelligence that is the most sensitive to brain damage. The other form of intelligence, refered to as intelligence B, has to do with the retention and use of intellectual products rather than with their original acquisition. The finding of poor performance of both hemiplegic groups on visual-spatial tasks may reflect a deficit in intelligence A, which is a general effect, rather than a result of reorganization of cerebral dichotomy.

### (iv) Treatment

There was no main effect on cognitive data for 'treatment', nor was it a significant predictor of cognitive outcome measures on multiple regression analysis.

## (F) Other Variables

Of all the variables investigated, developmental delay (measured as age at walking) emerged as the most significant predictor of cognitive outcome measures. It is presumed that this variable reflects the severity of motor involvement as well as intellectual impairment in hemiplegia. Perlstein et al. (1957) found that mental deficiency was the most important factor in delayed onset of walking. Function of the affected hand, which is mostly a measure of motor dysfunction only, was not a significant predictor. Walking after the age of two probably forecasts difficulties in cognitive and neuro-motor development.

It is also interesting to note that complications during pregnancy, rather than birth asphyxia, was the other significant predictor of cognitive outcome. The implication that congenital hemiplegia is related to intra-uterine events cannot be ignored, and an insult before birth may have severe implications for cognitive development. The possibility that birth asphyxia may be merely a sign of intra-uterine brain damage, has already been highlighted.

## (G) Summary and Conclusions

The present study was able to demonstrate that there is not a simple relationship between the side of cerebral lesion and the resultant cognitive deficits found on psychometric testing. Subjects who had sustained an early left hemispheric lesion (RHP) had longer latencies on tasks requiring comprehension of complex syntax. They also had significant deficiencies on some visual-perceptual tasks, demonstrated on some of the Performance subtests of the WISC and the Raven's Progressive Matrices, than the Controls. The latter difficulties had not been anticipated from a review of research on reorganization of lateralized cognitive functions after unilateral brain damage. On the other hand, right-lesioned subjects (LHP) had a consistent but nonsignificantly poorer performance on visual-spatial tasks and also general superior verbal skills (as measured on the WISC-R), compared to Controls. Generally though, the differences between the two hemiplegic groups on the various outcome measures, were not impressive, although the direction of the trends were consistent throughout the study.

Sex differences, familial sinistrality and 'treatment received' were not found to be significant modifying variables, nor were gestational age, birthweight and the severity of the hemiplegia as measured by affected hand function. A consistent effect for the presence of seizures or the brain damage as shown on CT scan could not be demonstrated. Only developmental delay and problems during pregnancy were identified as significant predictors of cognitive outcome. A limitation of this study is that the effects of memory (except for the Digit Span subtest on the WISC-R), attention (except as reported by the parents), abstract reasoning and problem solving on cognitive performance, have not been considered in detail. It is acknowledged that these factors may have been important to explain some of the cognitive deficits identified in this study (Taylor, 1988). It is hoped that because the three groups were comparable on many independent variables, that these factors were evenly distributed within the groups.

In conclusion, it is possible to propose two explains for the results found in the present study. The first hypothesis is based on a notion of limited plasticity (with implications of inter- and intrahemispheric reorganization) in a brain in which a left-right maturational gradient is present (Corballis et al, 1978). The more mature a structure is at the time of injury, and by implication less plastic, the less it would be able to take on new functions.

In congenital right hemiplegia the cerebral insult is in the left hemisphere, causing a transfer of handedness from the left to the right hemisphere (left hand dominant). In such cases, the speech center is more inclined to move to the right hemisphere too (interhemispheric reorganization). This restitution may be effective, but incomplete (Kohn, 1980), as demonstrated in the present study. Right hemiplegics did not perform markedly poorer on most verbal tasks than the Controls, but they had significant longer latencies on the Active-Passive Test, demonstrating some compromised language functioning. Possibly because of the importance of language, its development in the contralateral hemisphere took place at the cost of visual-spatial growth (Ogden, 1989). The resultant deficits of visual-spatial skills seen in the RHP would then represent an unsuccessful attempt at right intrahemispheric reorganization. This would explain the unexpected, but significant visual-spatial deficiencies demonstrated in the RHP (also found by Kershner et al., 1974). In the case of early right hemispheric lesions (LHP), transfer of visual-spatial functions to the intact, but more mature (and less plastic) left hemisphere is less likely. The language skills of this group remains relatively intact, while an intrahemispheric reorganization of right hemisphere functions, provides plasticity, if somewhat compromised, for visual-spatial skills.

Theoretically, any factor that may influence the maturity gradient, could also modify the reorganization of lateralized hemispheric functions after early brain damage. Sex and familial sinistrality may be such variables, though in the present study no main effects for either of these two factors could be shown. Possible reasons for the lack of these effects have already been discussed.

An alternative hypothesis suggests that the poor performance of both hemiplegic groups on visual-spatial tasks may not be due to cerebral reorganization of dichotic functions at all, but may reflect an effect of early brain damage on 'intelligence A', which is presumed to be responsible for visual-spatial functions. Effects of memory, attention and abstract reasoning could have been important predictors of cognitive outcome measures and were not specifically investigated in the present study. The uneven distribution of the prevalence of prematurity and the incidence of seizures both deserve further attention.

## (H) Implications for Future Research

The possibility that a similar study on later acquired cerebral lesions could demonstrate sex or familial sinistrality effects has been discussed before. The problem with the interpretation of the results in a population of subjects with later brain damage is the variability of the age of insult. Even if that could be controlled for, the wide range of possible cerebral damage and etiology makes it exceedingly difficult to collect a sample of subjects that are directly comparable.

Even in the present study, where the goal was to collect as homogenous sample as possible, the results indicate the possibility of two pathological processes involved. An insult during pregnancy may be an important predictor of general cognitive outcome and tests of language ability, whereas birth asphyxia might be an important modifying variable in the development of visual-spatial skills. Birth asphyxia was also correlated with abnormal CT scans, seizures and abnormal EEGs, possibly signifying involvement of cortical structures. As this kind of research is by its nature post facto, it is difficult to distinguish between those subjects who sustained an insult in utero and those who were injured at birth. Even so, it may be important in further research on dichotomy and plasticity to differentiate between the two groups. No routine investigation is able to differentiate between the two at present, but large-scale epidemiological surveys should be able to identify important historical and clinical factors that may be able to do so.

In conclusion, let us consider one more speculation. The abundance of hypotheses to explain the underlying physiology of cerebral dichotomy is an indication that no one theory is capable of explaining all the outcomes of the various research paradigms. None of them has been proven (or disproved) in clinical research. One factor that has not been considered to date, and could be very important, is the maturational gradient (i.e. that the left hemisphere matures more rapidly than the right). When the infant is born, the two hemispheres could be at different stages of neuronal differentiation. The right hemisphere would be trailing behind the left in the advent of neuronal death and selective synapse elimination. Both these processes have been shown to be important steps in cerebral maturation. The newborn infant is not only exposed to auditory images right from birth, but also visual stimuli (e.g. the mother's face). One could speculate that it is the presence of the different levels of synaptic elaboration and cell numbers in the two cerebral hemispheres at birth, that might cause the apparent dichotomy of cognitive functions. Many theorists have, in one model or another, argued that the organization of the left hemisphere is more discrete or focal and the right more diffuse. Could it be that the abundance of synapses and neurons in the right hemisphere affords it to be more suitable for visual-spatial functions, and the more mature left hemisphere's structure make it more ideal for verbal abilities? The left-right gradient is a relative one, and differs from subject to subject so that apparent dichotomy is relative too. This could explain the wide variation and often opposing results in dichotomy research. An exciting advantage of this approach is that soon it may be possible to measure the extent of synaptic elaboration and activity with magnetic resonance imaging spectrometry. Synaptic activity could then be related to specific clinical paradigms (e.g., auditory evoked potentials) to see if indeed perceived dichotomy develops secondary to the maturity gradient. This hypothesis could only be considered speculative at best, but it does have its roots in measurable anatomic and physiological processes.

In closing, a cautionary note from John Hughlings Jackson (1882, p 41), "The confusion of the anatomy and physiology of the nervous system with psychology is the bane of both neurology and psychology. It leads to superficial simplifications, and to crude popular explanations most of which are purely verbal".

In order to test "crude popular explanations", clinical researchers must concentrate on the investigation of specific groups of subjects, where variables are as effectively controlled as possible. By slowly piecing together the 'truths' and ruling out "superficial simplifications", it may be possible to develop an holistic picture of cerebral functioning and reorganization after early brain damage. With this study, it is hoped that some contribution has been made towards this goal, even if for the present many questions remain unanswered. Yet, it is these unanswered questions that will hopefully lead to innovative new research paradigms and the reevaluation of old ones.

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## APPENDIX

Code ______________

I.D. ______________

## LATERALIZATION IN CONGENITAL HEMIPLEGIA

### PARENT QUESTIONNAIRE II

Date ______________

This information will be kept strictly confidential.

A) PREGNANCY

1) Mother's total number of pregnancies: ______________

miscarriages: ______________

stillbirths: ______________

2) This child is pregnancy number: ______________

3) Were there any concerns or complications during this pregnancy?

yes _____ no _____

If yes, please describe:

______________________________________________

4) Were any medications prescribed during pregnancy:

yes _____ no _____

If yes, please describe:

______________________________________________

______________________________________________

## B) BIRTH INFORMATION

1) Date of birth: ________________________

2) Place of birth: Hospital: ________________

City: ________________

Province/Country ________________

3) Duration of pregnancy (in weeks): ________________

4) Was it a normal vaginal delivery? yes ________ no ________

| If not, was | yes | no |
|---|---|---|
| i) it a caesarian section? | ________ | ________ |
| ii) a breech delivery? | ________ | ________ |
| iii) anesthetics used? | ________ | ________ |
| iv) it an instrument delivery? | ________ | ________ |
| v) it a premature labour? | ________ | ________ |
| vi) labour induced? | ________ | ________ |
| vii) there fetal distress? | ________ | ________ |
| viii) it a prolonged labour? (greater than 12 hours) | ________ | ________ |
| ix) a twin pregnancy? | ________ | ________ |
| x) there any other problems? | ________ | ________ |

If yes to any of the above, please elaborate: ________________

________________________________________

________________________________________

| 5) After birth: | yes | no |
|---|---|---|
| i) did (s)he have difficulty breathing? | __________ | __________ |
| ii) was oxygen required? | __________ | __________ |
| iii) was an incubator required? | __________ | __________ |
| iv) was (s)he admitted to ICU? | __________ | __________ |
| v) did (s)he need artificial ventilation? | __________ | __________ |
| vi) was (s)he jaundiced (yellow)? | __________ | __________ |

If yes to any of the above, please elaborate: __________

__________

__________

__________

6) Apgars at birth (if known) __________

| | | %iles |
|---|---|---|
| 7) Birthweight (if known) | __________ | __________ |
| height (if known) | __________ | __________ |
| skull circumference (if known) | __________ | __________ |

C) DEVELOPMENT

1) At what age did each of the following occur?

(i) Head held up __________

(ii) Turned over __________

(iii) Sat alone __________

(iv) Crawled __________

(v) Pulled up __________

(vi) Walked __________

(vii) Fed self ______

(viii) Talked single words ______

(ix) Talked sentences ______

(x) Bowel control ______

(xi) Bladder control ______

2) Does (s)he appear to see well? yes ____ no ____

If no, please describe: ______

______

3) Does (s)he appear to hear well? yes ____ no ____

If no, please describe: ______

______

D) MEDICAL HISTORY

1) At what age was hemiplegia first suspected? ______

2) At what age was the diagnosis confirmed? ______

3) Was there an obvious cause? yes ____ no ____

If yes, please describe: ______

______

______

4) Has (s)he ever suffered from a seizure disorder/epilepsy?

yes ____ no ____

5) If yes, when did convulsions begin? ______

What medication is (s)he on? ______

______

Are the convulsions well controlled? (less than two convulsions per year?) yes ______ no ______

Any comments? ____________________

____________________

____________________

6) Has an EEG been done? yes ______ no ______

If yes, where and when was it done? ____________________

Did the EEG show abnormalities? yes ______ no ______

If yes, please describe (if known): ____________________

____________________

7) Has a brainscan been done? yes ______ no ______

If yes, where and when? ____________________

____________________

____________________

8) Was the brainscan normal ____________

abnormal ____________

9) Does (s)he have any other medical problems?

yes ______ no ______

If yes, please describe: ____________________

____________________

____________________

10) Is (s)he using any medication at present?

yes ______ no ______

If yes, please list: ____________________

____________________

____________________

## E) SCHOOL HISTORY

1) Present grade: ______________________________

2) Name of school: ______________________________

3) Type of class if other than regular: ______________________________

______________________________

4) At what age did (s)he start attending school? ______________

5) Did (s)he attend playschool/daycare/kindergarten?

yes _____ no _____

If yes, please describe: ______________________________

______________________________

______________________________

6) Has (s)he ever failed a grade? yes _____ no _____

If yes, please describe: ______________________________

______________________________

______________________________

7) Has (s)he encountered difficulties with schoolwork?

yes _____ no _____

If yes, please describe: ______________________________

______________________________

______________________________

8) How would you rate his/her performance at school?

| | excellent | above average | average | below average | poor |
|---|---|---|---|---|---|
| Written language | | | | | |
| Oral language | | | | | |
| Spelling | | | | | |
| Oral comprehension | | | | | |
| Reading comprehension | | | | | |
| Math | | | | | |

9) Has any professional help ever been sought for learning/school difficulties? yes _____ no _____

If yes, please describe briefly: ______________________

______________________

______________________

10) Are any of these resource specialists seeing your child?

| | yes | no |
|---|---|---|
| (i) Speech Pathologist | ________ | ________ |
| (ii) Counsellor/Social Worker | ________ | ________ |
| (iii) Remedial Teacher | ________ | ________ |
| (iv) Psychologist | ________ | ________ |
| (v) Occupational Therapist | ________ | ________ |

(vi) Physical Therapist __________ __________

(vii) School Nurse __________ __________

(viii) Pediatrician __________ __________

If yes, please describe: ______________________________

______________________________________________

______________________________________________

11) Has there been concern with attention deficit?

yes _____ no _____

If yes, please describe: ______________________________

______________________________________________

______________________________________________

12) Is (s)he on, or did (s)he ever receive Ritalin?

yes _____ no _____

13) Is (s)he using any aids/devices at school because of the physical handicap? yes _____ no _____

If yes, please describe: ______________________________

______________________________________________

______________________________________________

14) Is, or was there ever a behaviour problem at school?

yes _____ no _____

If yes, please describe: ______________________________

______________________________________________

______________________________________________

15) Any other comments about schooling: ______________________________

__________________________________________________

__________________________________________________

__________________________________________________

## I) MISCELLANEOUS

1) Total family income per year (mark the appropriate)

Less than $30,000 CDN ____________________
$30,000 - $40,000 CDN ____________________
$40,000 - $50,000 CDN ____________________
$50,000 - $60,000 CDN ____________________
$60,000 - $70,000 CDN ____________________
More than $70,000 CDN ____________________

2) Father's highest educational qualification. ____________________

__________________________________________________

3) Father's occupation/career/profession. ____________________

__________________________________________________

4) Mother's highest educational qualification. ____________________

__________________________________________________

5) Mother's occupation/career/profession. ____________________

__________________________________________________

6) Is anybody in your immediate family left handed (parents and children only) or ambidextrous?

yes ______ no ______

If yes, please describe: ______________________________

Thank you very much for completing the questionnaire